

ASPECTS OF THE BIOFOULING OF SALMON  
AQUACULTURE NETS IN SOUTHWESTERN  
NEW BRUNSWICK

CENTRE FOR NEWFOUNDLAND STUDIES

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ANTHONY DAVID HALL









**ASPECTS OF THE BIOFOULING  
OF SALMON AQUACULTURE NETS  
IN SOUTHWESTERN NEW BRUNSWICK**

by

© Anthony David Hall

A thesis submitted to the School of Graduate Studies  
in partial fulfillment of the requirements  
for the degree of Master of Science

Department of Biology  
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## **ABSTRACT**

A study of net fouling at three geographically distinct salmon farms in southwestern New Brunswick showed that during the summer production period (May-October), fouling communities were comprised of common members of the local flora and fauna. These results were similar to the observations of local salmon farmers, which suggests the potential value of these anecdotes as a source of fouling data. Analyses of relative abundance showed that the composition of communities was variously influenced by the time of year, location, and depth, but not by surface treatment. The application of a non-toxic antifouling wax to the nets showed no significant impact on species abundance, but did significantly reduce accumulated biomass throughout the production period. Also, the growth form of fouling organisms suggested that algae recruit to nets as spores and vegetative fragments, and invertebrates recruit as larvae and juveniles. The results also showed that biomass is not a particularly useful measure of fouling for operational purposes. Resistance to water flow due to the growth form of organisms is the primary operational impact of net fouling, and future research efforts should concentrate on quantification of this factor.

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## TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
1. INTRODUCTION	1
1.1 Fouling Organisms	3
1.2 Development of Fouling Assemblages	4
1.2.1 Colonization potential	5
<i>Algae</i>	5
<i>Invertebrates</i>	7
1.2.2 Dispersal	8
<i>Algae</i>	9
<i>Invertebrates</i>	11
1.2.3 Recruitment	12
<i>Algae</i>	13
<i>Invertebrates</i>	17
1.3 Study Background	19
1.4 Questions	23
2. MATERIALS AND METHODS	24
2.1 Study Sites	24
2.2 Study Units	24
2.2.1 Net frames	24
2.2.2 Net panels	26
2.2.3 Net treatment	27
2.3 Study Periods	27
2.4 Sampling Procedures	28
2.4.1 In-field sampling	28
2.4.2 Composition of fouling assemblages	28
<i>Taxonomic analyses</i>	29
<i>Relative abundance</i>	29
2.4.3 Accumulated biomass	30
2.5 Data Analysis	30
2.5.1 Analysis of relative abundance	31
<i>Kruskal-Wallis test of site independence</i>	31
<i>Chi-square test of treatment, depth and study period</i>	31

2.5.2 Analysis of biomass data	31
<i>Test for heterogeneity of variance</i>	32
<i>Randomized block analysis by study period (site 3)</i>	32
<i>Analysis of variance (sites 1 and 2)</i>	33
<i>Calculation of confidence limits</i>	34
<i>Economic decision rule</i>	35
2. RESULTS	37
3.1 Fouling Organisms	37
3.1.1 Chlorophyceae	37
3.1.2 Phaeophyceae	39
3.1.3 Rhodophyceae	41
3.1.4 Invertebrates	43
3.2 Temporal and Spatial Analyses	45
3.2.1 Depth effects	46
3.2.2 Study period effects	48
3.2.3 Site effects	49
3.3 Growth Form and Reproductive Status	51
3.3.1 Growth form	51
<i>Algae</i>	51
Chlorophyceae	51
Phaeophyceae	53
Rhodophyceae	56
<i>Invertebrates</i>	58
3.3.2 Reproductive status	59
<i>Algae</i>	59
Chlorophyceae	59
Phaeophyceae	60
Rhodophyceae	60
<i>Invertebrates</i>	61
3.4 Biomass Accumulation	61
3.4.1 Heterogeneity of variance	61
3.4.2 Analysis of variance (site 3)	62
3.4.3 Analysis of variance (sites 1 & 2)	63
<i>Site 1</i>	64
<i>Site 2</i>	65
3.5 Main Effects	65
3.5.1 Study period effects	65
<i>Site 1</i>	65
<i>Site 2</i>	67
3.5.2 Treatment effects	67

3.5.3 Treatment/study period effects	68
<i>Site 1</i>	69
<i>Site 2</i>	71
3.5.4 Depth effect	71
<i>Site 1</i>	71
<i>Site 2</i>	71
3.6 Confidence Limits	72
3.6.1 Economic decision rule	73
4. DISCUSSION	75
4.1 Fouling Community Composition	75
4.1.1 Fouling organisms	75
4.1.2 Temporal patterns	76
4.1.3 Treatment effects	76
4.1.4 Depth effects	77
4.1.5 Study period effects	78
4.1.6 Site effects	80
4.2 Growth Form and Reproductive Status	81
4.2.1 Growth form	81
<i>Algae</i>	82
<i>Invertebrates</i>	84
4.2.2 Reproductive status	84
<i>Algae</i>	85
<i>Invertebrates</i>	85
4.3 Biomass Accumulation	86
4.3.1 Experimental design	87
4.3.2 Analysis of variance (sites 1 & 2)	88
Study period effects	88
Treatment effects	89
Treatment/study period effects	89
<i>Site 1</i>	90
<i>Site 2</i>	90
Depth effects	91
4.3.3 Economic Analysis of Easy-Net™	91
4.4 A Final Note: fouling predictions	93
5. CONCLUSIONS	95
6. REFERENCES	97

## LIST OF FIGURES

<b>Figure 1</b>	Location of study sites in Passamaquoddy Bay, New Brunswick	25
<b>Figure 2</b>	Diagram of net panel configuration	26
<b>Figure 3</b>	Field program comprised of five study periods	27
<b>Figure 4</b>	Mixed assemblage of basally-attached green, red and brown algae	52
<b>Figure 5</b>	Mixed assemblage of Scytosiphonales and Ulvales	53
<b>Figure 6</b>	Mixed assemblage of entangled Chlorophytes and Phaeophytes	54
<b>Figure 7</b>	Assemblage of basally-attached and entangled green and red algae	55
<b>Figure 8</b>	Mixed assemblage dominated by <i>Scagelia pylaisei</i>	56
<b>Figure 9</b>	Typical accumulations of the hydroids	57
<b>Figure 10</b>	Accumulations of juvenile <i>Mytilus edulis</i>	58
<b>Figure 11</b>	Mean $\log_e$ biomass by study period for sites 1 and 2	66
<b>Figure 12</b>	Mean $\log_e$ biomass on treated and control panels at sites 1 and 2	68
<b>Figure 13</b>	Site 1 mean $\log_e$ biomass on treated and control panels	69
<b>Figure 14</b>	Site 2 mean $\log_e$ biomass on treated and control panels	70
<b>Figure 15</b>	Mean $\log_e$ biomass by depth at sites 1 and 2	72

## LIST OF TABLES

<b>Table 1</b>	Randomized complete block analysis for site 3 $\log_e$ biomass data	32
<b>Table 2</b>	Analysis of variance for site 1 and 2 $\log_e$ biomass data	33
<b>Table 3</b>	Catalogue of macrofouling chlorophytes	38
<b>Table 4</b>	Catalogue of macrofouling phaeophytes	40
<b>Table 5</b>	Catalogue of macrofouling rhodophytes	42
<b>Table 6</b>	Catalogue of macrofouling invertebrates	44
<b>Table 7</b>	Analysis of relative abundance	47
<b>Table 8</b>	Randomized blocks analysis of site 3 $\log_e$ biomass data	62
<b>Table 9</b>	ANOVA of site 1 $\log_e$ biomass data	64
<b>Table 10</b>	ANOVA of site 2 $\log_e$ biomass data	64
<b>Table 11</b>	% biomass reduction limits for Easy-Net™ wax	72

## LIST OF APPENDICES

<b>Appendix 1</b>	Relative abundance data
<b>Appendix 2</b>	Descriptions of growth form and reproductive status



## 1. INTRODUCTION

The fouling of aquaculture nets is a persistent operational concern to salmon farmers in southwestern New Brunswick, and it must be actively managed to avoid a range of potentially costly consequences. Net fouling contributes to the fatigue and failure of equipment, which in turn leads to the escape of fish, increased incidence of disease, and reduced production (Smart 1981, Knights 1985, Beveridge 1987).

Considering the breadth of potential negative implications, there has been little scientific interest in net fouling. Published data are sparse (Milne 1970, 1975ab, Lovegrove 1979), and for southwestern New Brunswick are limited to a preliminary study of the effects of fouling on dissolved oxygen concentrations (Bevan 1987), an *ad hoc* list of fouling organisms at an experimental site (Sutterlin *et al.* 1981), and a preliminary survey of net fouling at several commercial farms (Hall *et al.* 1989).

In southwestern New Brunswick, net fouling is considered an operational problem during the annual 'summer' production period, which spans from the beginning April until the end of October. When this study was initiated in 1988, nets were typically changed on a calendar basis, approximately every two months. This period became standardized in the industry following the banning of organotin net antifoulants, after which producers had to rely on physical methods to manage fouling. The choice of this period is a compromise

between minimizing the high costs associated with repeatedly changing nets, and local experience that fouling is unlikely to reach operationally critical levels in this period.

The observations of farm operators represent a valuable untapped source of operationally relevant fouling data, although descriptions of organisms tend to be made in colloquial terms. Farmers recognize that the time at which nets are submerged, and the presence of antifoulants, affects both the type and quantity of fouling organisms throughout the production period. They also recognized that similar patterns of fouling occurred at approximately the same time each year.

Traditionally, the farmers recognize seasonal increases. These observations can be broadly summarized as an early spring growth of “slime” (diatoms), a late spring growth of “sea grass” (Ulva) and “brown hair” (Ectocarpales), a summer growth of “wire weed” (hydroids), mussels (*Mytilus*) and “brown grass” (Scytosiphonales), an early fall growth of hydroids and mussels, and a late fall growth of hydroids. With regard to the effects of antifoulants, experience with highly effective organotin coatings had established high performance expectations amongst farmers. The prevailing attitude at the time this study was initiated was, ‘if an antifoulant allows more than a surface “slime”, then it isn’t working’. A final anecdote with potential relevance to net fouling is the common observation of farm operators that large quantities of “drift weed” regularly become entangled in aquaculture nets.

This introduction constructs an ecological and operational framework within which to consider these observations with respect to net fouling. It first presents an overview of typical benthic colonization and describes mechanisms involved in the fouling of nets. The next section outlines the study with respect to the aquaculture industry at the time the work was conducted. Lastly there is a statement of the specific questions addressed by the thesis.

### **1.1 Fouling Organisms**

The number of marine plants and animals which have been catalogued as fouling organisms ranges from 2000 (WHOI 1952) to 4000 (Crisp 1974). The most conspicuous are macroalgae and sessile macroinvertebrates, although typical marine fouling assemblages also include a variety of microorganisms (Zobell & Allen 1935, Mitchell & Kirchman 1984), microalgae (Round 1971, Pyne *et al.* 1986), microscopic forms of macroalgae (Santelices 1990, Vadas *et al.* 1992) and macroinvertebrates (Osman *et al.* 1992, Osman & Whitlatch 1995), and motile animals which shelter amongst and feed on the fouling (Hidu *et al.*, 1981; Beveridge, 1987; Underwood & Anderson, 1994; Osman & Whitlatch, 1995). The precise composition of marine fouling assemblages reflects the temporal and spatial variability typical of community development processes (Dayton 1984, Scheltema & Carlton 1984, Underwood & Denley 1984, Underwood & Fairweather 1989, Santelices 1990, Hurlbut 1991, Turner & Todd 1993, Boero 1994, Underwood & Anderson 1994).

In temperate western Atlantic waters, a relatively small number of macroalgae and sessile macroinvertebrates have been reported as fouling organisms (Hidu *et al.* 1981, Sutterlin *et al.* 1981, Whittick *et al.* 1982, Drinnan 1984, Hall *et al.* 1989). In each case, the species composition reflects the unique temporal and spatial contexts of the work. Generally, the most conspicuous fouling organisms in a region tend to be amongst the most common and widely distributed members of the flora and fauna (WHOI 1952, Scheltema & Carlton 1984). Their success at colonizing both natural and anthropogenic substrates reflects the typically broad ecological range of their reproductive and survival strategies.

### **1.2 Development of Fouling Assemblages**

Marine fouling assemblages are complex, dynamic systems. Developmentally, they exhibit the same typically broad temporal and spatial variability as benthic communities on natural substrates (Sutherland & Karlson 1977, Sousa 1979ab, Keough & Downes 1982, Schoener 1984, Sutherland 1984, Underwood & Denley 1984, Hurlbut 1991, McCook & Chapman 1991, 1993, Anderson & Underwood 1994, Underwood & Anderson 1994), much of which is attributable to the largely unpredictable effects of the biological and physical environment on reproduction, dispersal, settlement, recruitment, competition, vigour and mortality (Dayton 1984, Scheltema & Carlton 1984, Underwood & Denley 1984, Roughgarden *et al.* 1988, Underwood & Fairweather 1989, Santelices 1990, Hurlbut 1991, Norton 1992, Vadas *et al.* 1992, Boero 1994, Underwood & Anderson 1994, Anil *et al.* 1995). The body of work on these subjects is large, and it is beyond the

scope of this introduction to attempt a comprehensive review. Similarly, it is beyond the scope of this study to address these myriad potential influences experimentally. The following presents a brief sequential overview of key mechanisms involved in the development of fouling communities up to the establishment of settled algal and invertebrate propagules. Where key points are addressed, a selection of key references are provided, should the reader wish to explore issues in greater depth.

In a mechanistic sense, the successful establishment of a fouling assemblage requires several conditions and processes. There must first be a source of material which has the potential to be liberated from its parent population. It must have the attributes necessary to become established on a substrate (colonisation potential), it must be transported from its source (dispersal), become attached to a substrate (attachment), and survive sufficiently long to be recorded (recruitment).

### **1.2.1 Colonization potential**

#### ***Algae***

Algae may colonize as spores or vegetative fragments (Round 1981, Hoffman 1987, Santelices 1990, Fletcher & Callow 1992, Norton 1992, Vadas *et al.* 1992). For a discussion of the energetics and evolutionary implications of reproductive strategies see Santelices (1990).

Vegetative fragments represent a potentially significant source of colonizing material (Clokic & Boney 1980, Kennelly & Larkum 1983). Some algae produce specialized vegetative reproductive structures (e.g. *Sphacelaria* branchlets (South & Whittick 1987, Santelices 1990)), and in the case of the rhodophyte *Rhodochorton purpureum*, fragmentation is considered to be the principle reproductive strategy (Pearlmutter & Vadas 1978). Vegetative fragments can also be dislodged from parent populations due to the actions of waves and currents (Denny 1988, Santelices 1990, Fletcher & Callow 1992), grazers (Mshigeni 1978, Fletcher & Callow 1992), and disease (Santelices 1990). Material is then dispersed, and may become established (Fager 1971, Round 1981, Kennelly & Larkum 1983, Santelices 1990, Fletcher & Callow 1992, Norton 1992).

Specialized reproductive and dispersal stages of macroalgae include gametes and spores (usually termed zoospores or swimmers in the Chloro- and Phaeophyceae, and carpospores and tetraspores in the Rhodophyceae) (Fletcher *et al.* 1984, Hoffman 1987, South & Whittick 1987, Santelices 1990, Fletcher & Callow 1992). Whereas the liberation of vegetative algal propagules can occur throughout the year, reproduction of macroalgae in temperate regions tends to exhibit distinct seasonality. Some species are fertile throughout the year (Hehre & Mathieson 1970, Whittick *et al.* 1989), whereas others exhibit reproduction in one or more specific seasons (Hehre & Mathieson 1970, Mathieson & Hehre 1983, Hoffman 1987, Whittick *et al.* 1989).

### ***Invertebrates***

Invertebrate propagules with colonization potential are broadly grouped as larvae (Crisp 1984) and juveniles (Lane *et al.* 1982, 1985). Each encompasses a massive range of possibilities with regard to morphology, behaviour, and environmental interactions, many of which have yet to be investigated experimentally (Underwood & Denley 1984, Boero 1994, Underwood & Anderson 1994). Like the algae, the production, release, and recruitment of invertebrate propagules exhibits broad spatial and temporal variability, due to a wide range of biotic and abiotic factors and their interactions (WHOI 1952, Sutherland & Karlson 1977, Sutherland 1984, Underwood & Denley 1984, Harris 1990, Hurlbut 1991, Turner & Todd 1993, Underwood & Anderson 1994).

In light of the prominence of mussels and hydroids in anecdotal descriptions of net fouling in southwestern New Brunswick, and reports from the literature that they are typical net fouling constituents (Milne 1975ab, Sutterlin *et al.* 1981), it is appropriate to focus here on aspects of the colonization potential of the most common mussel recorded, the blue mussel (*Mytilus edulis* L.) and some typical examples of hydroids. In mussels, both motile, planktonic veligers (Harris 1990, Lutz & Kennish 1992) and small, post-larval juveniles (Lane *et al.* 1982, 1985) have colonization potential. Amongst the hydroids, larval propagules are the primary colonization unit. In thecate genera (e.g. *Obelia*), motile, non-feeding, planulae larvae are liberated from free-floating, planktotrophic hydromedusae (Brusca & Brusca 1990, Harris 1990). The propagules of athecate genera (e.g. *Tubularia*) are motile, planktotrophic actinulae larvae (Brusca & Brusca 1990, Harris 1990).

### 1.2.2 Dispersal

Both macroalgae and invertebrates can be dispersed by passive and active mechanisms (*see* Scheltema & Carlton 1984, Santelices 1990, Norton 1992). Passive mechanisms are considered to account for larger-scale dispersal (Santelices 1990), from local coastal transport to extension of biogeographic boundaries (Scheltema & Carlton 1984, Carlton & Hodder 1995). Active mechanisms act in much smaller spatial scales, and are limited primarily to local movements of motile propagules (Crisp 1984, Cloney & Torrence 1984, Santelices 1990). By contrast, there are a wide range of passive mechanisms, including transport of floating propagules (Norton & Mathieson 1983, Pearlmutter & Vadas 1978, Norton 1992), rafting on a variety of objects (Foster & Whilan 1975, Scheltema & Carlton 1984, Carlton & Hodder 1995), ingestion and excretion by animals (Buschmann & Santelices 1987, Santelices 1992), and attachment to plants (Carlton & Scanlon 1985) and animals (Mathieson 1992).

Water is either directly or indirectly the dispersal medium for marine organisms. Water transports propagules away from 'parent' populations by bulk flow, principally as coastal and oceanic currents (Scheltema & Carlton 1984, Denny 1988, Reed *et al.* 1988, Santelices 1990, Norton 1992). Water can also transport free-floating (Bonsdorff 1992, Norton 1992) and rafted populations of mature individuals (Santelices 1990). As sources



of reproductive and vegetative material, free-floating and rafted populations have similar colonization potentials to coastal populations (Norton & Mathieson 1983).

Much of the dispersive success of marine organisms is determined by the physical and physiological attributes of propagules, and their ability to survive until they become attached to a substrate (Crisp 1984, Harris 1990, Santelices 1990, Norton, 1992). The distance propagules travel while remaining viable has been termed the 'dispersal shadow' (Norton 1992). Both macroalgae and invertebrates have developed a range of structural and behavioural adaptations which allow them to extend their dispersal shadows.

### *Algae*

As mentioned, algal propagules include both fragments of dislodged plants and specialized reproductive units (*see* Hoffman 1987, Santelices 1990). Free-floating fragments have high dispersive potential, both in terms of distance and numbers of species (Santelices 1990, Norton 1992). For example, John (1974) reported drift dispersal of *Ascophyllum nodosum* over 5500km, and Clokie & Boney (1980) recorded approximately 25% of the local flora entangled in a filamentous substrate after a five week exposure period. This high dispersive potential is based on the ability of fragments to remain photosynthetic and physiologically vigorous in a free-floating state (Norton & Mathieson 1983, Bonsdorff 1992), and retain the capability to re-attach to substrates (Round 1981, Santelices 1990, Fletcher & Callow 1992). Dispersive capabilities, and therefore colonizing potential, are further enhanced if detached material can produce spores

(Santelices 1990, Fletcher & Callow 1982, Norton 1992). Although the majority of drifting forms are not considered capable of becoming reproductive (Norton & Mathieson 1983), some may either become fertile *en route* (Norton 1992), or already bear mature reproductive structures when they are dislodged (Santelices 1990).

In contrast to vegetative fragments, algal spores have poor dispersive potential. They have a comparatively short viability (Kain 1964, Jones & Babb 1968, Deysher & Norton 1982), due to limited food reserves (Kain 1964, Santelices 1990, Norton 1992), and possess no known capacity for dormancy (Santelices 1990). Reports of spore viability range from 24 hours for *Ectocarpus* (Baker 1971 in Fletcher & Callow 1992), to 8 days for *Enteromorpha* gametes (Jones and Babb 1968), and 11 days for one species of both *Gelidium* and *Porphyra* (Hoffman & Camus 1989). Most are reported to occupy the lower end of the scale (Santelices 1990). For a discussion of algal spore viability, see Santelices (1990).

The primary dispersal mechanisms of algal micropropagules are drifting, sinking and swimming (Norton 1992). Drift accounts for large-scale dispersals (Hoffman 1987, Denny 1988), although the dispersal shadow is relatively small by comparison to that possible for drifting fragments. For example, Amsler and Searles (1980) reported *Enteromorpha* spores 35km from the nearest recorded parent population. As a function of velocity and time, the distance spores drift is largely determined by ambient oceanographic conditions during and after their release. Water bodies are typically stratified into regions with

temporally and spatially distinct velocity and turbulence patterns (see Denny 1988). On a smaller spatial scale, both the sinking and swimming behaviours of spores are affected by stratified flow and turbulence, the physical character of spores, the physico-chemical state of the water, and various biotic and abiotic interactions (see review Santelices 1990).

### *Invertebrates*

Like algae, the dispersal potential of invertebrates is dictated primarily by water movements, and the ability of organisms to remain viable until they arrive at a suitable substrate (Day & McEdward 1984, Scheltema & Carlton 1984).

Over long-distances, dispersal typically involves the passive transport of larvae and juveniles (Scheltema & Carlton 1984, Seed & Suchanek 1992). Typically, invertebrate larval forms, such as actinulae of the athecate fouling hydroid *Tubularia* (Harris 1990), and veligers of *Mytilus edulis* (Lutz & Kennish 1992), are dispersed by coastal and oceanic currents. A potentially important dispersal mechanism in *M. edulis* is bysso-pelagic migration (Lane *et al.* 1982, 1985). Small ( $\leq 2$  mm long) post-larval forms can repeatedly detach and disperse using specialised byssus threads. Mussels may take two months to attain a length of 2 mm (Lutz & Kennish 1992), which suggests bysso-pelagic drift may account for long distance dispersal (Lane *et al.* 1982, 1985). Like the transport of reproductive algal fragments, dispersal can also involve drift of reproductive 'parent' forms. An example is the thecate hydroid *Obelia* sp., which is dispersed over long distances as free-swimming hydromedusae (Harris 1990, Brusca & Brusca 1990), which subsequently produce motile planula larvae which colonize the substrate (Crisp 1984,

Brusca & Brusca 1990, Harris 1990). The dispersal of invertebrates over smaller distances involves both passive transport by water, and active swimming (Scheltema & Carlton 1984, Harris 1990 ).

To survive during dispersal, invertebrate larvae and juveniles typically feed on plankton (planktotrophic) and/or rely on stored food reserves (Crisp 1984, Harris 1990). These mechanisms allow larvae to survive for longer periods, and disperse further, than algal spores (Day & McEdward 1984, Harris 1990, Lutz & Kennish 1992). Another important adaptation of larvae is an ability to delay metamorphosis until conditions are suitable (Crisp 1984). There is also evidence that larvae receive nutrition by absorption of dissolved organics and consumption of detritus (Bayne 1983, Manahan *et al.* 1983, Day and McEdward 1984).

### **1.2.3 Recruitment**

Recruitment describes the mechanistic continuum of post-dispersal settlement, attachment and establishment of organisms on substrates (Keough & Downes 1982, Osman *et al.* 1992). Recruitment is a descriptive concept which differentiates between the organisms which initially settle on a substrate, and those which survive and are observed at some later time (Keough & Downes 1982, Santelices 1990, Hurlbut 1991). Quantitative studies of recruitment are rare (Osman *et al.* 1992), presumably due to the technical challenges of conducting microscopic sampling in the field.

The composition of an assemblage at any moment in time reflects the outcome of a series of interacting, developmental processes (Underwood & Denley 1984, Boero 1994). For any assemblage of organisms, if observations are time independent and there are no data on initial settlement or subsequent processes, then settlement and recruitment cannot be differentiated.

### *Algae*

The recruitment behaviours of algal spores are greatly influenced by interactions between the physical and behavioural characteristics of spores, the physical and chemical character of substrate surfaces, and the physical and biotic nature of the immediate environment (Fletcher *et al.* 1984, Santelices 1990, Fletcher & Callow 1992, Vadas *et al.* 1992).

In the boundary layer, directly adjacent to the substrate, the settling of algal spores is influenced by the thickness of the boundary layer, and the size and mobility of spores. The sinking rate of non-motile spores is related primarily to their size and density (Okuda & Neushul 1981, Hoffman & Camus 1989), although shape, the presence of extracellular mucilage, and degree of aggregation, and the density of the water have been shown to have various effects (Coon *et al.* 1973, Boney 1975, Amsler & Searles 1980, Okuda & Neushul 1981, Hoffman 1987, Hoffman & Camus 1989, *see review* Santelices 1990). Motile spores of green and brown algae may respond actively to abiotic and biotic stimuli

in order to locate a suitable attachment site (Santelices 1990, Fletcher & Callow 1992). For example, spores of *Ectocarpus* (Müller 1964 in Fletcher & Callow 1992) and *Enteromorpha* (Christie 1973) were reported to exhibit discriminatory exploratory behaviour before attaching to substrates. The most widely reported abiotic factors involved with site selection relate to substrate characteristics (*see* Santelices 1990, Fletcher & Callow 1992).

In general, motile spores are thigmotactic and favor rough rather than smooth surfaces (Christie 1973, Foster 1975, Neushel *et al.* 1976). Motile spores may also exhibit differential phototacticity (Baker & Evans 1973, Christie 1973) and chemotacticity (Fletcher & Callow 1992). Positive and negative phototacticity of gametes and zoospores have been related to reproductive strategies and small-scale dispersive behaviours in the water column, but these interpretations may overestimate the directional swimming abilities of motile spores in open water, where ambient flow and turbulence is several orders of magnitude greater (Denny 1988). Chemotacticity has been related primarily to gametic attraction processes (Müller 1981), although Amsler & Neushel (1989) also reported spore motility along organic and inorganic chemical gradients. The latter evidence supports the hypothesis that the settlement of algal spores, like many invertebrate larvae (Mitchell & Kirchman 1984), involves chemical components of conditioned substrates (Fletcher & Callow 1992).

The attachment of algal spores typically occurs in two stages; an initial, reversible attachment, and then permanent bonding (Fletcher *et al.* 1984, Santelices 1990, Fletcher & Callow 1992). In both cases, attachment involves production of an extracellular adhesive. Although extracellular polysaccharide mucilage (Chamberlain & Evans 1973, Scott & Dixon 1973) appears to play some role in the initial attachment of spores (Bråten 1975, Fletcher & Callow 1992), there is substantial evidence that initial attachment and orientation of motile spores involves flagella/substrate bonding, and subsequent flagellar absorption/axonemal retraction (Gunn *et al.* 1984, Fletcher & Callow 1992). It is likely that extracellular mucilage is responsible for the initial attachment of rhodophyte spores (Boney 1975, Ngan & Price 1979, Santelices 1990, Fletcher & Callow 1992). After initial attachment, spores become permanently bonded to the substrate by secreting a glycoproteinaceous adhesive (Chamberlain & Evans 1973, Callow & Evans 1974, Bråten 1975) which increases in strength over time as it cures (Chamberlain & Evans 1973, Bråten 1975).

Once attached, spores typically pass rapidly (Fletcher & Callow 1992) through a series of discrete developmental stages as they become established on the substrate (Fletcher *et al.* 1984, Fletcher & Callow 1992). To summarize, attached spores develop a cell wall (Christie 1973), establish polarity (Evans *et al.* 1982) and germinate (Fletcher *et al.* 1984, Fletcher & Callow 1992). A wide range of germination patterns have been reported (*see* Fletcher & Callow 1992), but typically rhizoidal initials develop from basal regions of spores, and shoots or filaments develop from distal regions. The growth of primary and

secondary rhizoids increases the purchase of plants on substrates. Their character is influenced by the physical and chemical character of substrates, particularly topography, surface energy, and surface chemistry. Topographically, the more uneven the surface, the greater the attachment area and penetration by rhizoids (Foster 1975, Neushel *et al.* 1976, Harlin & Lindbergh 1977, DeNicola & McIntire 1990). Both substrate surface energy and chemistry of the attachment of fouling organisms are important bases of the antifoulant industry (*see* Fischer *et al.* 1984), and can influence the growth form and adhesive strength of rhizoids (Fletcher 1976, 1988, Fletcher & Baier 1984, Fletcher *et al.* 1984, 1985).

The ability of organisms to become established is largely a function of their ability to withstand the physical and biological pressures they are subjected to after they have become attached to a substrate. Generally, spores experience high mortality (Vadas *et al.* 1992) due to a range of abiotic and biotic factors, including sedimentation, water flow, grazing and environmental exposure (*see* Santelices 1990, Vadas *et al.* 1992). Both sedimentation and scour are important sources of mortality (Dayton 1975, Neushel *et al.* 1976), but the former may also provide nutrients, and therefore enhance survival (Kenelly 1983). The dislodgement of propagules by water is a function of water velocity, and substrate and spore characteristics. Typically, spores establish more successfully on rough surfaces in low velocity flow (Norton 1983, Pearson & Evans 1990, Vadas *et al.* 1992). For example, Norton and Fetter (1981) reported that *Sargassum muticum* propagules exposed to low velocity flow established randomly, whereas at higher velocities they were



found primarily in depressions. Another major source of mortality is grazing of attached spores (Miller & Vadas 1984, Watson & Norton 1985, 1987) and early, post-attachment developmental forms (Miller & Vadas 1984, Vadas *et al.* 1992, Osman & Whitlatch 1995). Grazing may be reduced by substrate features which provide shelter (*see* Vadas *et al.* 1992), and also influence herbivore behaviour (Underwood & Jernakoff 1981).

### ***Invertebrates***

Like algae, invertebrate recruitment is influenced by a wide range of abiotic and biotic factors (*see* Crisp 1984, Roberts *et al.* 1991). In an evolutionary sense, the wide range of complex responses of invertebrate larvae to environmental cues help them find the most suitable location for the next phase of their life cycle. Not surprisingly, they tend to recruit to the types of habitats occupied by parent populations (Lindner 1984).

Many invertebrate larvae are motile, and actively explore substrates before settling (Crisp 1974, 1984, Lindner 1984). The selection of an attachment site (Keough & Downes 1982) may be influenced by ambient environmental factors including flow, pressure, light, color, and substrate characteristics (*see* Crisp 1974, 1976, 1984), and various chemical cues (Cloney & Torrence 1984, Crisp 1984, Morse 1984). Like algae, invertebrate attachment normally involves a temporary, reversible, initial stage, followed by permanent bonding

(Crisp 1984, Lindner 1984). Initial attachment by various mucilage mechanisms (Lindner 1984) allows larvae to explore or detach from substrates (Crisp 1984, Lindner 1984). Permanent bonding typically involves the secretion and hardening, or 'curing', of an adhesive (Crisp 1984, Lindner 1984).

The initial attachment of *Mytilus edulis* relies on sticky mucous secreted by the foot (Lindner 1984, Lutz & Kennish 1992). The attachment is weak, and a more robust attachment by byssus threads occurs rapidly (Bayne 1983, Lutz & Kennish 1992). Byssal attachment can act as both a temporary and permanent mechanism (Bayne 1983). Mussels can release their byssal attachment, and migrate across substrates (Lindner 1984), or disperse through the water column (Lane *et al.* 1982, 1985). The actinulae larvae of athecate hydroids such as *Tubularia*, and the planulae of thecate species like *Obelia*, attach rapidly to substrates by discharging adhesive nematocysts on making contact with substrates (Müller *et al.* 1976, Lindner 1984). Roberts *et al.* (1991) report that the larvae of *Tubularia* and *Obelia* species form permanent bonds within one hour. As with the attachment mechanism of mussels, if conditions become unsuitable, the attachment structure can be broken, and the larvae can move on (Roberts *et al.* 1991).

The settlement, attachment and establishment of invertebrates can be influenced by the biological and physico-chemical character of the substrate (Crisp 1984, Roberts *et al.* 1991, Anderson & Underwood 1994). Established microscopic and macroscopic forms of organisms can release chemicals which are reported to stimulate settlement of larvae

(Lindner 1984, Mitchell & Kirchman 1984, Maki *et al.* 1988, 1989). Typical examples include the conditioning of substrates by bacteria (Mitchell & Kirchman 1984) and various gregarious or associative settlement behaviours (Crisp 1984, Lindner 1984). Physical and chemical characteristics of surfaces which are reported to affect larval recruitment and subsequent growth include texture, contour and shape (Crisp 1984), surface energy (*see* Rittschof & Costlow 1989), and surface chemistry (Crisp 1984, Roberts *et al.* 1991).

Responses to substrate characteristics are often organism-specific (Crisp 1984, Rittschof & Costlow 1989). For example, Roberts *et al.* (1991) reported barnacle and bryozoan larvae favoured wettable surfaces, whereas the settlement of the larvae of the hydroids *Tubularia* and *Obelia* was independent of surface energy. Mussels are widely reported to settle initially on filamentous substrates (Bayne 1964, Lutz & Kennish 1992, Seed & Suchanek 1992), although recent studies question whether this behaviour is common (Lasiak & Barnard 1995).

### **1.3 Study Background**

The primary motivation for my study was to address the paucity of data on net fouling organisms and fouling mechanisms, but within a clear operational context. At the time the study was initiated, the salmon aquaculture industry was a major economic contributor in southwestern New Brunswick, with 54 salmon sea farms in the Passamaquoddy region, providing gross revenues of approximately \$8,000,000 CAD. The

economic importance of the industry provided a climate where financial support was available to investigate issues with operational relevance.

In 1988, the use organotin net antifoulants was banned due to growing concerns of environmental persistence of the most widely used compounds. Without tin-based net antifoulants, operators were left with only physical options to manage fouling.

Physical management of net fouling is costly and labour intensive. For example, the cost of net fouling on a typical twenty cage farm in 1988 was approximately \$38,000CAD. These additional costs of production came at a time when the international over-supply of farmed salmon was narrowing profit margins. To deal with the problem of net fouling, research was undertaken in two main areas. The priority was to investigate the performance of several non-toxic net coatings which were entering the marketplace, with the hope of filling the vacuum left by the ban on organotin antifoulants. These products were expensive and untested under local conditions, and the industry was resistant to assuming their cost until performance could be clearly demonstrated. Of these, only Easy-Net™, a non-toxic petroleum-based wax, had received regulatory approval for commercial use at the time this study was initiated. There was also interest in pursuing opportunities with the potential to improve the efficiency of physical net fouling management programs. One possibility was the development of integrated net fouling management strategies, similar to those used to manage many agricultural pests. Agricultural integrated pest management (IPM) strategies are based on the establishment of economic thresholds for pests. These are defined as the level of some pest characteristic, for example population size, which has

negative economic implications on a production system (Sill 1982). The characteristic is monitored, and when the economic threshold is passed, management strategies are implemented. In salmon farming, the changing of nets on a calendar basis, typically every two months, was based primarily on logistic considerations, and not the 'fouling state' of the nets.

It was hoped that investigations of the temporal and spatial nature of net fouling composition and development would highlight opportunities to establish economic thresholds for fouling, and ultimately lead to the development of integrated net fouling strategies. This study was designed to simultaneously address both these areas of interest. It was recognized from the outset that the initiative to evaluate 'new' net antifoulants was the industry priority. As such, the study program would have to deal with the inherent resistance of salmon farmers to these products on economic grounds, and in many ways, the methodology for this study was dictated by this consideration.

Resistance amongst farm operators to the use of new antifouling products was based primarily on skepticism of the promotional claims of manufacturers, and to the prevalence of adequate cost-effective fouling control using physical methods. Resistance to change is a typical characteristic of conservative, capital-intensive industries (Lamble 1984) such as fish farming. Based on experience addressing similar attitudes in agriculture, operationally-orientated, highly visible field trials of new products produce acceptance (Lamble 1984). With this aim, trials at three typical operations, which would follow a standard two month

net cleaning schedule, were implemented. Farm staff were also kept fully aware of the status of the project. To secure the cooperation of producers, it was also important that the methodology cause minimum interference with day-to-day farm operations. As the field program required periodic boat transport of personnel and equipment to cage sites, it was important that study units were an appropriate size to be loaded and unloaded from small boats, and could be handled without the need for assistance from farm personnel. A final consideration for the size and placement of study units was the need for high visibility of field trials to farm operators and their personnel. A preliminary net fouling study (Hall *et al.* 1989) established that a logistically-appropriate size for study units was one meter square, and that the least intrusive and most visible location was adjacent to the outside face of predator nets, suspended vertically in the water column.

When this study was conducted, the ban on organotin antifoulants had created interest in alternative net coatings, such as Easy-Net™, and the refinement of net fouling management strategies. However, since then, a number of effective copper-based net antifoulants have been introduced, and they are used on most salmon farms. Consequently, there is little current interest in net fouling, and the operational relevance of this thesis is minimal.

#### **1.4 Questions**

The questions addressed by this thesis arise from the stated operational interests of the aquaculture industry for both performance evaluations of net antifoulants and characterizations of the spatial and temporal character of net fouling.

The components of the thesis which deal with the antifouling performance of Easy-Net™ wax consider (1) the effect of the coating on the accumulated biomass and relative abundance of fouling organisms at the end of five, two-month periods. The temporal scale was chosen to reflect typical net changing schedules of salmon farms in southwestern New Brunswick. The evaluation includes a standardised methodology to assess the economic viability of antifoulants with respect to physical net management costs. In a broad sense, the ecological focus of this thesis addresses the general paucity of information on net fouling. It considers; (2) the influences of geographic location, (3) season, (4) net treatment, and (5) depth on the accumulated biomass and relative abundance of fouling organisms. It also considers the value of (6) the growth form of fouling organisms and (7) reproductive status as indicators of colonization strategies and potentials.

## **2. MATERIALS AND METHODS**

### **2.1 Study Sites**

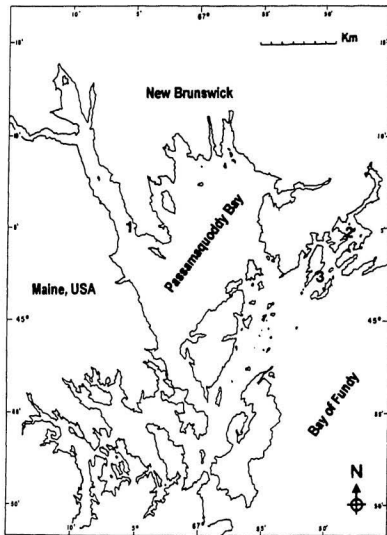
The study was conducted at three coastal salmon farms in the Passamaquoddy region of southwestern New Brunswick, Canada (Figure 1). Site 1 was the experimental farm at the Huntsman Marine Science Center, situated in a small sheltered cove in the outer reaches of the St. Croix river estuary (#1, Fig.1). Site 2, the Jail Island site, was a medium-sized commercial farm located in a sheltered location in the Letang River estuary, on the northeast coast of the Letang peninsula (#2, Fig.1). The third site was the Seafarm Canada Frye Island farm, a large operation located in an exposed cove on the southeast coast of Frye Island (#3, Fig.1).

### **2.2 Study Units**

#### **2.2.1 Net frames**

The basic study unit was a one meter square frame constructed from 2.25 inch diameter black ABS drainage pipe (Figure 2). 10mm holes were drilled at 10cm spacing down opposite sides of each ABS frame pipe. Two 10cm stainless steel eye-bolts were fastened at opposite ends of the top frame member as hanging points. A 4kg piece of ferrous steel chain was fastened as a weight to the opposite, bottom member.

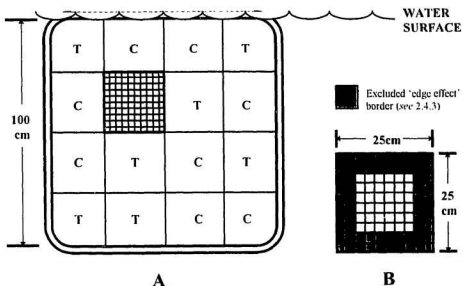




**Figure 1** Location of study sites in Passamaquoddy Bay, southwestern New Brunswick, Canada. 1, HMSC site ( $45^{\circ} 5'$ ,  $67^{\circ} 5'$ ); 2, Jail Island site ( $45^{\circ} 4'$ ,  $66^{\circ} 48'$ ); 3, Seafarm Canada Frye Island site ( $45^{\circ} 3'$ ,  $66^{\circ} 51'$ )

### 2.2.2 Net panels

Each net frame was strung with sixteen 25cm by 25cm panels (625cm<sup>2</sup>) of 3.6cm (diagonal) knotless nylon aquaculture netting arranged in a *Randomised Complete Block Design* (Little & Hills 1978) (Figure 2). Each row was comprised of two antifoulant treated and two untreated (control) panels. Each net panel was comprised of one hundred (10 x 10) net 'mesh squares'. Net panels were fastened to each other and the frame with locking nylon wire ties.



**Figure 2** A. Illustration of *Randomized Complete Block* configuration of net panels suspended vertically in ABS polymer frame (C - control, T - treatment). B. Enlarged individual net panel (10 X 10 mesh) showing two row excluded border (see 2.4.3).

### 2.2.3 Net treatment

Half of the net panels in each frame were soaked in Easy-Net™ wax for half an hour, drained, and hung vertically to cure for 48 hours. The product is an air-cured, petroleum distillate-based, net wax which is intended to reduce the quantity of fouling and facilitate net cleaning. The cured product is benign, and is classified by Agriculture Canada as a barrier system, and not an antifoulant (*Rex Toxopeus pers. comm.* ).

### 2.3 Study Periods

The field program was conducted from May through October, 1989, to coincide with the period when salmonids typically accumulate body weight most rapidly (Beveridge 1987). The field program was divided into five overlapping periods (Fig. 3), each approximately eight weeks in length.

STUDY PERIOD	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
1	-----					
2		-----				
3			-----			
4				-----		
5					-----	

Figure 3 Field program comprised of five study periods.

## **2.4 Sampling Procedures**

To satisfy fundamental requirements for subsequent one-way analyses of variance, all sampling was destructive and time independent (Underwood 1981).

### **2.4.1 In-field sampling**

At the end of each study period, frames were recovered from each site, net panels excised, placed in polythene bags, and transported in a cooler to the Huntsman Marine Science Center. In the lab, panels were stretched on a 25cm by 25cm polypropylene tube frame (0.75" diameter) and placed carefully in cooled seawater in a shallow plexiglass tank. This was done to minimize deterioration and handling damage of samples.

The plexiglass tank was illuminated from below by four 40watt fluorescent tubes, from above by two 600 watt tungsten spot lights, and panels were examined with a 10X dissecting binocular microscope. Detailed taxonomic examinations were performed under higher magnification.

### **2.4.2 Composition of fouling assemblages**

The analysis of composition of fouling organisms was restricted to macroalgal and sessile macroinvertebrate components. Constituent organisms on each panel were keyed to genus or species, and assigned a relative abundance rating (Appendix 1).

### ***Taxonomic analyses***

Where possible, macroalgae were keyed to species using South and Hooper (1980). Systematics and nomenclature followed South and Tittley (1986), and South *et al.* (1988). Sessile macroinvertebrates were identified according to Brinkhurst *et al.* (1976), and with the assistance of the Bill Hogans of the Atlantic Reference Center, St. Andrews, New Brunswick, Canada. Systematics and nomenclature followed Brusca and Brusca (1990).

When required for further study, samples were preserved in 5% formalin in seawater (5% solution to minimize decomposition of ubiquitous microinvertebrates, and potentially deterioration of the algal material (Bill Hogans *pers. comm.*)). For fine structure, slides (50% Karo solution) were examined at 25x and 100x magnification.

### ***Relative abundance***

Organisms were assigned subjective relative abundance ratings (Fletcher 1980a, Sutterlin *et al.* 1981) of Present, Common or Abundant, according to the following visual criteria. A rating of present was assigned for at least one occurrence on a panel (e.g. *Enteromorpha*, Figure 4), common when there were distinct aggregations of a species (e.g. *Scagelia*, Figure 4, and *Scytosiphon*, Figure 4), and abundant when one or more species were clearly predominant on a panel (e.g. *Petionia* and *Scytosiphon*, Figure 5, and *Scagelia*, Figure 8 ).

### **2.4.3 Accumulated biomass**

Accumulated biomass was determined by sub-sampling and weighing standardised sub-units (nodes) from each panel.

Prior to sub-sampling, a perimeter border of two squares was excluded from each 10 by 10 square net panel to reduce potential 'edge effects' (Foster 1975, Little & Hills 1978). The remaining 36 squares were delineated into 25 nodes, each comprised of the 'cross' intersect and half the length of each of the four perpendicular radiating arms of net twine. As such, each of these nodes represented  $1/110^{\text{th}}$  of the two-dimensional area of each net panel. Six were selected at random, excised, laid flat for five minutes on standardized absorbent paper, and weighed to two decimal places.

Accumulated biomass for nodes was corrected by subtraction of  $1/110^{\text{th}}$  of the mean weight of ten unfouled, drained net panels. Treated and control data were corrected accordingly.

### **2.5 Data Analysis**

Statistical analyses encompassed  $\chi^2$  and Kruskal-Wallis (Kruskal & Wallis 1952) analyses of relative abundance, and univariate ANOVA of biomass data. Statistical analyses were performed using APL+ statistical software (STSC Inc.).

### 2.5.1 Analysis of relative abundance data

Relative abundance data were analyzed to investigate spatial and temporal variability in the composition of net fouling assemblages. Prior to analyses, relative abundance ratings (Appendix 1) were *rank-ordered* as: **Absent = 1, Present = 2, Common = 3, and Abundant = 4.**

#### *Kruskal-Wallis test of site independence*

A Kruskal-Wallis test was applied to investigate site independence (Kruskal & Wallis 1952, Goldman & Weinberg 1985). In contrast to using  $\chi^2$  to test for site independence, Kruskal-Wallis is more sensitive, particularly to elucidate shifts in median values between sites.

#### *Chi-square test of treatment, depth and study period effects*

Where the Kruskal-Wallis indicated no significance between sites, data were pooled across sites and were tested by  $\chi^2$  for depth and study period effects.

### 2.5.2 Analysis of biomass data

Studentized raw data yielded a skewed distribution with a long upper tail. A  $\log_e$  transform gave a near symmetry, although the distribution was rather flat. The central limit theorem applies, and all raw biomass data was  $\log_e$  transformed to stabilize the variance (Snedecor & Cochran 1967).

### *Test for heterogeneity of variance*

Standard deviations for each site were tested for heterogeneity using Bartlett's test for homogeneity of variance (Bartlett 1937, Little & Hills 1978).

**Table 1** Randomized complete block analysis for site 3 log<sub>e</sub> biomass data.

Source	d.f.
1. Treatment	1
2. Residual column effect	2
3. Depth of panel effect (row effect)	3
4. Treatment x Depth interaction	3
5. Error	6
6. Total	15

### *Randomized block analysis by study period (site 3)*

The results of Bartlett's test for site 3 indicated heterogeneity. Consequently, the analysis for site three was limited to a separate randomized complete block analysis for each study period. The residual column effect (#2, Table 1) is merely an estimate of error, assuming it has no obvious biological interpretation, and is included primarily as a test for procedural error. It was tested for significance against error (#5, Table 1) at a 1% significance level (not significant unless  $F(2,6) > 10.92$ ). This ensures that with a probability of 99%, the residual column effect will not be erroneously declared significant for any of the combined panel data for any one month. Where there was no



significance, the residual column effect sum of squares and degrees of freedom were combined with error to increase the power of the analysis.

**Table 2** Analysis of variance for site 1 and 2 log<sub>e</sub> biomass data

Source	d.f.
1. Study period	4
2. Treatment	1
3. Treatment x Study period interaction	4
4. Residual column effect	2
5. Residual column effect x Study period	8
6. Depth of panel effect (row effect)	3
7. Depth x Study period	12
8. Treatment x Depth	3
9. Treatment x Depth x Study period	12
10. Error	30
11. Total	79

#### *Analysis of variance (sites 1 and 2)*

As with the randomized complete block analysis, the residual column effect (#4, Table 2) and its interaction with study period (#5, Table 2) should not be significant unless there are serious errors with the execution of the study protocol. Both were tested against error (#10, Table 2) at a 1% significance level (not significant unless  $F(\text{residual } [2,30]) > 5.39$  and  $F(\text{residual} \times \text{study period } [8,30]) > 3.17$ ). Where there was no significance, both were combined with error to increase the power of the analysis.

### *Calculation of confidence limits*

The prime operational motivation for conducting the preceding analyses was to determine whether the antifoulant net treatment reduced accumulated biomass, and what was the magnitude of any effect. Confidence limits were calculated for biomass data.

The 'true' or untransformed percent reduction ( $\rho$ ) in biomass was calculated by:

$$\rho = 100 (1 - \delta)$$

Where  $\delta = \beta_s / \beta_c$ , and  $\beta_s$  and  $\beta_c$  are the 'true' mean biomass for the antifoulant and control respectively.

The estimate of  $\ln(\delta) = \ln(\beta_s) - \ln(\beta_c)$  given by the difference ( $d = b_s - b_c$ ) between the mean  $\log_e$  biomass under the two conditions has optimum properties which other estimators (e.g. the raw data) do not have. The corresponding estimate of the percent reduction in biomass ( $r$ ) is:

$$r = 100 (1 - \exp(-d))$$

The estimated variance of  $b_s$  and  $b_c$  for sites 1 and 2 is 1/40 the overall error mean square (each represents the mean of 40 values). For site 3, where there is no common error term,

the variances are 1/200 the sum of the error mean squares (randomized blocks analyses) across study periods. The variance of  $d$  is the sum of the variances of  $b_s$  and  $b_e$ .

The  $(1-\alpha)$  percent confidence limit for  $\ln(\delta)$  is:

$$d - s_d t(\alpha, v) < \ln(\delta) < d + s_d t(\alpha, v)$$

Where  $t(\alpha, v)$  is the Student's  $t$  for  $\alpha$  with  $v$  degrees of freedom, and  $s_d$  is the standard deviation of  $d$ . Confidence limits were calculated for  $\alpha = 99.9\%$  confidence level.

#### *Economic decision rule*

An economic decision (integer) rule was applied to determine if the use of the antifoulant would be economically efficacious in light of fouling management costs at the time (1989/1990). Use of the antifoulant is considered worthwhile if:

$$f_c - f_s > A/D$$

Where  $f_c$  and  $f_s$  are the number of changes required *per net* to adequately manage fouling with and without an antifoulant respectively.  $A$  is the cost of treating a standard aquaculture net with Easy-Net™ (\$420CDN), and  $D$  is the 1989/1990 cost of cleaning a standard net manually (\$400CDN). As  $f_c$  and  $f_s$  are integers, a maximum reasonable value

for **A** and a minimum reasonable value for **D** were calculated to make any management decision arising from the analysis more clear cut.

### 3. RESULTS

#### 3.1 Fouling Organisms

Fouling assemblages were comprised of macroalgae, sessile macroinvertebrates, and microfouling. The most varied component was the macroalgae, with a total of twenty seven species (Tables 3-5). The sessile macroinvertebrate component was sparse, with one species of bivalve and three genera of hydroids (Table 6). There were also a number of motile invertebrates (Table 6) and various levels of microfouling (primarily diatoms and detritus) on all panels.

##### 3.1.1 Chlorophyceae

In total, 13 species of Chlorophyceae were recorded throughout the five study periods (Table 3). The largest number of species in any single period was 9, recorded at the end of the May/June period. There was a trend towards greater numbers of species of chlorophytes at site 1 than at sites 2 and 3 (Table 3). The main exception was August/September where only five species were recorded at site 1, while four and nine species were recorded at sites 2 and 3 respectively. Also, there was little difference in the number of species at all three sites at the end of the June/July period (Table 3).

The most widely occurring species of chlorophytes were *Cladophora sericea* (Hudson) Kuetz., *Chaetomorpha linum* (O.F. Muell.) Kuetz., and *Rhizoclonium riparium* (Roth)



Kuetz. ex Harvey, *Enteromorpha intestinalis* (L.) Link, *E. linza* (L.) J.Agardh, *E. prolifera* (O.F.Muell.) J.Agardh, and *Ulva lactuca* L. (Table 3).

The least widely distributed taxa were *Spongomorpha aeruginosa* (L.) Hoek and *Spongomorpha* sp., which occurred in the middle three study periods. *Ulothrix flacca* (Dillwyn) Thuret in LeJolis occurred only in the first period, an unidentified species of *Blidingia* in the third period at site 1, and an isolated specimen of *Urospora wormskioldii* (Mert in Hornem) Rosenv. in the first period at site 3 (Table 3).

### 3.1.2 Phaeophyceae

A total of nine species of Phaeophyceae were recorded (Table 4). The lowest number of species was recorded for the May/June study period where three species were recorded at sites 1 and 2, and two species at site 3. There was little difference in the numbers of species from the other study periods (Table 4).

*Ectocarpus siliculosus* (Dillwyn) Lyngbye and *Pilayella littoralis* (L.) Kjellman were the most widely occurring phaeophytes. Both were recorded at each site in each study period. *Petalonia fasciata* (O.F.Muell.) O. Kuntze and *Scytosiphon lomentaria* (Lyngbye) Link were also widely recorded, although only *P. fasciata* was found on May/June panels, and not at site 3 (Table 4).





In contrast, four species of phaeophytes exhibited a distinct periodicity (Table 4). *Chordaria flagelliformis* (O.F.Muell.) Agardh (Chordariaceae) was recorded from August/September panels at sites 1 and 3 only. Similarly, *Chorda tomentosa* Lyngbye (Chordaceae) was recorded on July/August panels at sites 1 and 3 only. *Laminaria* sp. Lamouroux (Laminariaceae) was found only on June/July panels at site 3. *Dictyosiphon foeniculaceus* (Hudson) Grev. (Dictyosiphonaceae) was somewhat more widely distributed, occurring variously in the middle three study periods at sites 1 and 3 (Table 4).

### 3.1.3 Rhodophyceae

Seven species of Rhodophyceae were recorded (Table 5). The greatest number of species (six) was recorded on the August/September panels. The lowest number was recorded for the July/August study period, with three species at site 1, and only one each at sites 2 and 3. Other than the June/July period, greater numbers of species occurred at site 1 in each period (Table 5).

The most widely occurring species was *Polysiphonia flexicaulis* (Harvey) F. Collins. With the exception of site 2 in the first period (May/June), it was recorded at all sites throughout the five study periods (Table 5).

Three species of *Porphyra* (*P. miniata* (Agardh.) Agardh., *P. umbilicalis* (L.) J. Agardh., and one unidentified species) were variously distributed across all periods (Table 5).

Table 5 Catalogue of macrofouling rhodophytes recorded on net panels at the end of each study period (Site: 1=HMSC, 2=Jail Island, 3=Frye Island)

DIVISION CLASS Order Family Genus/species	STUDY PERIOD SITE	May/June			June/July			July/August			August/September			September/October		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
<b>RHODOPHYCOTA</b>																
<b>RHODOPHYCEAE</b>																
<b>Bangiales</b>																
<i>Porphyra minima</i> (Agardh.) Agardh.					+						+			+		
<i>Porphyra umbilicalis</i> (L.) J. Agardh.											+			+		
<i>Porphyra</i> sp. Agardh.		+	+	+							+					
<b>Ceramiales</b>																
<i>Antithamionella floccosa</i> (O.F. Muell.) Whitt.											+					
<i>Ceramium nodulosum</i> (L.) J. Agardh.											+					
<i>Scaglia pykasi</i> (Mont.) Wynne		+	+		+	+	+	+	+	+	+	+	+	+	+	+
<b>Rhodomeleaceae</b>																
<i>Polysiphonia flexicaulis</i> (Harvey) F. Collins		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<b>TOTAL</b>		<b>3</b>	<b>2</b>	<b>2</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>3</b>	<b>1</b>	<b>1</b>	<b>5</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>2</b>	<b>2</b>

*Scagelia pylaisei* (Mont.) Wynne was also recorded for all five periods, primarily at sites 1 and 3. At site 2 it was found only on the May/June and June/July panels (Table 5).

*Antithamnionella floccosa* (O.F. Muell.) Whittick and *Ceramium nodulosum* (Lightfoot) Ducluzeau, were not widely distributed. *C. nodulosum* was recorded at site 3 and site 1 on June/July and August/September panels respectively. *A. floccosa* was restricted to site 1 August/September panels (Table 5).

#### 3.1.4 Invertebrates

The sessile invertebrate component of the fouling assemblage was sparse in total numbers of species by comparison with the algae (Table 6). There were three species of hydroids, including the athecate *Tubularia crocea* (Agassiz) and *Bougainvillea carolinensis* (McCRady), and one unidentified thecate species of *Obelia*. The sole bivalve was the common fouling blue mussel *Mytilus edulis* L.

The lowest number of invertebrate species (2) was recorded for the May/June period. The August/September period had the greatest number with four. The remaining three periods had three species each (Table 6).

The most widely occurring invertebrate was *T. crocea*. The species was recorded from all study periods, although in June/July it didn't occur at site 3, and in May/June was found only at site 2. The other athecate species, *B. carolinensis*, was the least widely distributed

Table 6 Catalogue of sessile invertebrates recorded on net panels at the end of each study period (Site: 1=HMSC, 2=Jail Island, 3=Frye Island)

DIVISION CLASS Subclass Order Sub-order Family Genus species	STUDY PERIOD			May/June			June/July			July/August			August/September			September/October		
	SITE			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
<b>SESSILE INVERTEBRATES</b>																		
Cnidaria																		
Hydrozoa																		
Hydrasida																		
Hydrasida																		
Alcyonaria																		
<i>Tubularia crocea</i> (Agassiz)				+			+			+	+		+			+	+	+
<i>Bougainvillea carolinensis</i> (McCrady)				+														
Thesalia																		
<i>Ovella</i> sp.							+						+			+	+	+
MOLLUSCA																		
BIVALVIA																		
Acanthozaria																		
Mytilidae																		
<i>Mytilus edulis</i> L.							+			+	+		+			+	+	+
<b>TOTAL</b>	<b>0</b>	<b>2</b>	<b>0</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>4</b>	<b>3</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>2</b>

invertebrate, occurring at only one site from each of the May/June, July/August, and August/September periods. The thecate *Obelia* sp. occurred at all sites in the final two periods, and on the June/July panels at sites 1 and 2. The species was not recorded for May/June and July/August periods (Table 6).

The sole 'hard fouling' species, *Mytilus edulis*, was recorded for all but the first period. During the second period (June/July) it was not found at site 2, and was not recorded on September/October panels at site 3 (Table 6).

There were also a number of species of motile invertebrate recorded, although by definition they are not considered constituents of fouling assemblages and are not included in Table 6. Large numbers of unidentified species of *Caprella*, small amphipods and decapods were recorded throughout the five periods. Two species of nudibranch (*Coryphella rufibranchialis* Ascanius, and *Dendronotus frondosus* (Johnston)) were observed grazing on hydroids in all five periods. Isolated specimens of littorinids (*Littorina* spp.), were also found throughout the study

### **3.2 Temporal and Spatial Analyses**

The abundance of sessile species showed varying degrees of geographic, spatial and temporal variability, including site specificity, depth zonation and seasonal occurrence (Table 7). Relative abundance data for each study period are presented in Appendix 1 (Tables A1.1-1.5).

A comparison of total and treatment  $\chi^2$  ( $\chi^2_{\text{TOTAL}} = 27.78$ ;  $\chi^2_{\text{TREATMENT}} = 26.94$ ) indicated no difference in relative abundance of constituent species. Therefore, treatment and control data were pooled prior to subsequent depth, study period and site analyses.

### 3.2.1 Depth effects

Across all study periods, the distribution of green algae was distinctly influenced by depth (Table 7). *Cladophora sericea*, *Chaetomorpha linum*, *Rhizoclonium riparium*, *Enteromorpha intestinalis*, and *E. linza* showed a highly significant ( $P < 0.001$ ) trend of decreasing abundance with depth (Appendix I, Tables A1.1 - A1.5). *Ulva lactuca* exhibited an even more significant depth effect ( $P < 0.0001$ ). In all study periods *Ulva lactuca* was most prevalent on top row panels.

Two species of phaeophytes also showed a significant trend of decreasing abundance by depth (*Ectocarpus siliculosus* ( $P < 0.01$ ) and *Petalonia fasciata* ( $P < 0.001$ )). No Rhodophyceae or invertebrates exhibited depth effects.

**Table 7** Analyses of relative abundance of constituent fouling organisms by depth, study period (Chi<sup>2</sup>) and site (Kruskal-Wallis). (-, non-significant or insufficient occurrence; \*, P < 0.05; \*\*, P < 0.01; \*\*\*, P < 0.001; \*\*\*\*, P < 0.0001)

CLASS Order <i>Genus species</i>	DEPTH Chi <sup>2</sup> (3df)	STUDY PERIOD Chi <sup>2</sup> (4df)	SITE Kruskal- Wallace (2df)
<b>ALGAE</b>			
<b>CHLOROPHYCEAE</b>			
<b>Cladophorales</b>			
<i>Cladophora sericea</i>	27.78***	13.40**	10.50**
<i>Chaetomorpha linum</i>	33.68***	14.92**	-
<i>Rhizoclonium riparium</i>	23.45***	-	-
<b>Ulinales</b>			
<i>Ulvingia</i> sp.	-	-	12.53**
<i>Enteromorpha intestinalis</i>	21.17***	28.29***	6.78*
<i>E. linza</i>	25.60***	22.46***	9.55**
<i>E. prolifera</i>	8.32 *	40.42****	-
<i>Ulva lactuca</i>	49.19****	-	-
<i>Ulvaia obscura</i>	-	-	6.71*
<b>PHAEOPHYCEAE</b>			
<b>Dictyosiphonales</b>			
<i>Dictyosiphon foeniculaceus</i>	-	-	13.39**
<b>Ectocarpales</b>			
<i>Ectocarpus siliculosus</i>	11.86**	17.35**	16.04***
<i>Polysiphonia littoralis</i>	NS	NS	NS
<b>Scytosiphonales</b>			
<i>Petalonia fasciata</i>	28.84***	14.74**	-
<i>Scytosiphon lomentaria</i>	-	28.87***	29.05***
<b>RHODOPHYCEAE</b>			
<b>Bangiales</b>			
<i>Porphyra muricata</i>	-	-	15.18***
<i>Porphyra</i> sp.	-	48.44****	13.75**
<b>Ceramiales</b>			
<i>Polysiphonia flexicaulis</i>	-	44.39****	-
<i>Scagelia pelagica</i>	-	-	17.13***
<b>INVERTEBRATES</b>			
<b>HYDROZOA</b>			
<b>Hydroida</b>			
<i>Obelia</i> sp.	-	88.88****	-
<i>Tubularia crocea</i>	-	42.88****	15.64***
<b>BIVALVIA</b>			
<b>Anisomyaria</b>			
<i>Mytilus edulis</i>	-	39.43****	12.05**

### 3.2.2 Study period effects

The Chi<sup>2</sup> analysis of study period effects showed significance was more widely distributed than corresponding depth effects (Table 7). *Cladophora sericea* and *Chaetomorpha linum* showed the same degree of study period effect ( $P < 0.01$ ). *C. sericea* was less abundant in the first period (App.1, Table A1.1) than in the other four periods (App.1, Tables A1.2-1.5). In contrast, *C. linum* was generally more prevalent in the second (June/July) and third (July/August) periods (App.1, Tables A1.2 & A1.3).

Three species of Ulvales exhibited various levels of study period effects. Results for *Enteromorpha intestinalis* were highly significant ( $P < 0.001$ ), primarily due to low occurrence in the first study period (App.1, Table A1.1). *E. linza* and *E. prolifera* also showed significant study period effects ( $P < 0.001$  and  $P < 0.0001$  respectively), but in both cases the results are attributable to a relatively high abundance in the last period (App.1, Table A1.5).

The study period effect for *Ectocarpus siliculosus* and *Petalonia fascia* showed the same significance level ( $P < 0.01$ ) (Table 6). In both cases, there was an alternating cyclic trend in abundance between consecutive periods (App.1, Tables A1.1-1.5). The results for *Scytosiphon lomentaria* were also significant ( $P < 0.001$ ), and although there was no obvious differential pattern between periods where it occurred (App.1, Tables A1.2-1.5), it was absent from the first study period (App.1, Table A1.1).



Two species of rhodophytes, *Polysiphonia flexicaulis* and sporelings of an unidentified species of *Porphyra*, showed a highly significant study period effects ( $P < 0.0001$ ). Other than a few isolated occurrences in the third (July/August) and fourth (August/September) periods, *Porphyra* sp. occurred primarily in the first and last periods (App.1, Tables A1.1 & A1.5). *P. flexicaulis* was rare in the first period, but occurred widely in the other four (App.1, Tables A1.1-1.5).

The hydroids *Tubularia crocea* and *Obelia* sp. exhibited highly significant study period effects ( $P < 0.0001$ ) (Table 7). *T. crocea* occurred less abundantly in the first two periods (App.1, Tables A1.1&1.2) than in the last three periods (App.1, Tables A1.3-1.5). Similarly, *Obelia* sp. was more common in the last two periods (App.1, Tables A1.4&1.5) than in the first three periods (App.1, Tables A1.1-1.3). Results for *Mytilus edulis* were also highly significant ( $P < 0.0001$ ), with the species substantially less abundant in the first and last periods than the middle three (App.1).

### 3.2.3 Site effects

The Kruskal-Wallis analysis indicated significant site effects for many species (Table 7). *Cladophora sericea* and *Blidingia* sp. showed similar degrees of site effect ( $P < 0.01$ ) (Table 7), and in both cases occurred more abundantly at site 1 than sites 2 and 3. *Ulvaria obscura* showed a less significant effect ( $P < 0.05$ ), though it exhibited a similar abundance/site pattern. In contrast, *Enteromorpha intestinalis* ( $P < 0.05$ ) and *E. linza* ( $P < 0.01$ ), tended to occur more abundantly at sites 1 and 3 than at site 2.

Amongst the Phaeophyceae, *Dictyosiphon foeniculaceus* ( $P < 0.01$ ) and *Ectocarpus siliculosus* ( $P < 0.001$ ) also occurred more abundantly at sites 1 and 3 than at site 2. In contrast, *Scytosiphon lomentaria* was significantly more abundant ( $P < 0.001$ ) at site 3 than at sites 1 and 2.

Three species of rhodophytes exhibited significant site effects (Table 7). *Porphyra miniata* ( $P < 0.001$ ), *Porphyra* sp. ( $P < 0.01$ ) and *Scagelia pylaisei* ( $P < 0.001$ ) all occurred more abundantly at site 1 than at sites 2 and 3.

Of the two species of invertebrate having significant site effects (Table 7), *Tubularia crocea* had the highest significance level ( $P < 0.001$ ). Other than the occurrence of *T. crocea* at site 2 in the first study period, and not at sites 1 and 3 (App.1, Table A1.1), there was no clear differential site/abundance pattern. *Mytilus edulis* ( $P < 0.01$ ) tended to be more abundant at site 1 than at sites 2 and 3.

### 3.3 Growth Form and Reproductive Status

A range of growth forms and reproductive states was exhibited by fouling organisms throughout the five study periods (Appendix 2, Tables A2.1-2.5).

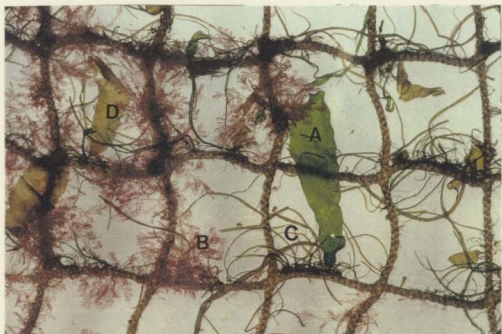
#### 3.3.1 Growth form

##### *Algae*

Two general algal growth forms were recorded (App. 2, Tables A2.1-2.5): thalli clearly attached to the substrate (Figure 4), and entangled forms (Figure 5). With densely entangled specimens, it was often difficult to determine whether attachment structures were present or not (Figure 6). Some species were recorded in only one form, whereas others occurred as both.

##### **Chlorophyceae**

The filamentous chlorophytes *Chaetomorpha linum*, *Rhizoclonium riparium*, *Urospora wormskioldii* and *Ulothrix flacca* were recorded only in unattached, variously tangled forms. *Cladophora sericea* occurred as entangled, unattached filaments in all five periods and as short, basally-attached filaments in the first period. *Spongomorpha* spp. occurred only as basally-attached tufts, and in the one occurrence of *Bhidingia* sp., it was clearly attached to the substrate.



**Figure 4** Mixed assemblage of small, basally-attached green, red and brown macrophytes. A. *Enteromorpha* sp.; B. *Scagelia pylatsei*; C. *Scytosiphon lomentaria*; D. *Petalonia facia*.

The three species of *Enteromorpha* were recorded in both forms, although *E. intestinalis* and *E. prolifera* occurred most commonly as heavily entangled aggregations of thalli without obvious attachments (Figure 7). In contrast, *E. linza* occurred primarily as basally-attached, short thalli. In all cases, the remaining species of Ulvales, *Ulva lactuca* and *Ulvaria obscura*, were clearly attached.

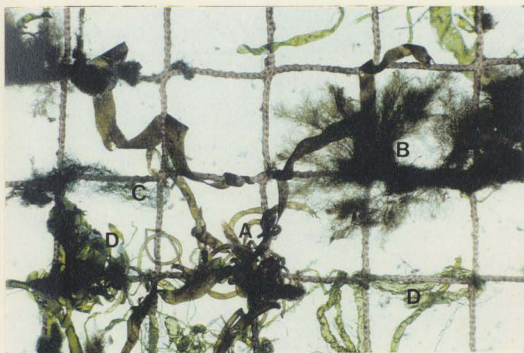


**Figure 5** Mixed assemblage of fouling macrophytes comprised primarily of the Scytosiphonales species *Petalonia fascia* (A) and *Scytosiphon lomentaria* (B) (Phaeophyceae), and a few Ulvales (Chlorophyceae) (C).

### Phaeophyceae

The typically highly entangled nature of thalli of both species of Ectocarpales, *Ectocarpus siliculosus* and *Pilayella littoralis*, and the high prevalence of surficial microfouling, made it extremely difficult to determine whether specimens were

attached directly to the substrate. There were instances where dense, localised accumulations occurred (Figure 6), which suggests primarily entangled thalli.



**Figure 6** Mixed assemblage of entangled chlorophytes and phaeophytes. **A.** *Scytosiphon lomentaria*; **B.** ectocarpoid (?); **C.** *Rhizoclonium riparium*; **D.** *Enteromorpha* sp.

Of the two recorded species of Scytosiphonales, *Petalonia fascia* occurred only as basally attached thalli. In a number of instances *P. fascia* thalli occurred in entangled aggregates, and although holdfasts were not visible, the growth form strongly suggests basal attachment (Figure 4). *Scytosiphon lomentaria* was recorded as both entangled and basally

attached forms. Like *P. fascia*, in some cases the attachment status of *S. lomentaria* was unclear due to occurrences of dense, entangled aggregations (Figures 5 & 6). The remaining phaeophytes (*Chordaria flagelliformis*, *Chorda tomentosa*, *Dictyosiphon foeniculaceus*, *Laminaria* sp.) occurred only as basally-attached forms.



**Figure 7** Assemblage of fouling macrophytes comprised primarily of basally-attached and entangled *Enteromorpha* spp. (Ulvaes), and the rhodophyte *Polysiphonia flexicaulis*

### Rhodophyceae

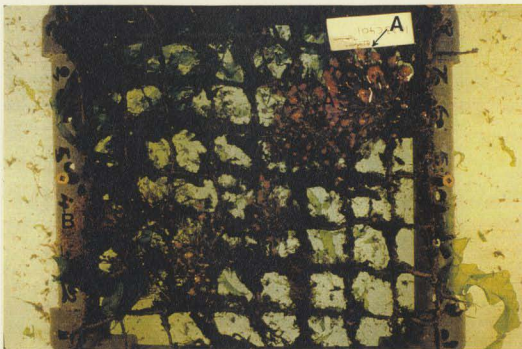
All recorded rhodophytes were attached to the substrate. *Porphyra miniata* and the small sporelings of *Porphyra* spp. were basally-attached. In contrast, *Porphyra umbilicalis* had typical centric holdfasts.



**Figure 8** Mixed assemblage of fouling macrophytes dominated by the rhodophyte *Scagelia pylaisaei* (Ceramiales), with scattered green, brown and red algae.



All species of Ceramiales (*Antithamnionella floccosa*, *Ceramium rubrum*, *Polysiphonia flexicaulis*, and *Scagelia pylaisaei*) were typically basally-attached (Figures 4, 7 & 8). In situations where the basal regions of thalli were obscured by microfouling accumulations, the typical erect arborescent or plumose growth form strongly suggested basal attachment.



**Figure 9** Typical examples of wirey, dense accumulations of the hydroids *Tubularia crocea* (A) and the more compact *Obelia* sp. (B)

### *Invertebrates*

The most common hydroid, *Tubularia crocea* occurred most commonly as dense, wirey aggregations, with the hydrocauli radiating from dense basal zones of attachment (Figure 9). There was also evidence of lateral rhizoidal spreading from 'parent' aggregations along adjacent net fibers. In contrast, *Obelia* sp. had a highly branched, arborescent growth form (Figure 9), arising from a single basal attachment.



**Figure 10** Accumulations of juvenile *Mytilus edulis* attached to surface of a dense understorey of predominantly entangled, filamentous chlorophytes

*Mytilus edulis* were anchored to nets and other fouling by byssal threads. In several cases, relatively large juvenile mussels constituted the outer component of fouling assemblages, attached to distal regions of underlying fouling (Figure 10). This stratified structural pattern suggests recruitment of juveniles rather than spat. Large numbers of juvenile *Mytilus* were observed suspended in the upper water column at site 3 at the end of the June/July study period.

### **3.3.2 Reproductive status**

#### ***Algae***

The majority of species appeared to be sterile, but in those that were fertile, a range of reproductive states were observed throughout the five study periods (Appendix 2, Tables A2.1-2.5).

#### **Chlorophyceae**

Specimens from the majority of species of chlorophytes were reproductive in one or more study periods (Appendix 2). Members of the Ulvales were the most widely reproductive. The majority of *Enteromorpha intestinalis* plants, from the May/June period, and *E. linza* plants from the September/October period, had clear, post-reproductive thalli. The most widely occurring zoosporic Ulvales was *Ulva lactuca*, with active release recorded during the June/July, August/September, and September/October periods. Zoosporic specimens of *E. intestinalis* were recorded during the

August/September period, and *E. linza* and *E. prolifera* from the August/September and September/October periods.

The filamentous Cladophorales, *Cladophora sericea*, *Chaetomorpha linum* and *Rhizoclonium riparium*, appeared to be reproductive only at the end of the August/September study period.

### **Phaeophyceae**

The only obviously reproductive phaeophytes were *Ectocarpus siliculosus* and *Pilayella littoralis*. Unilocular and plurilocular reproductive structures were recorded for *P. littoralis* throughout the five periods. Both types of structure were recorded for *E. siliculosus* during July/August and September/October periods. Only plurilocular structures were observed for the other three periods (Appendix 2).

### **Rhodophyceae**

All reproductive rhodophytes were tetrasporic, characterised by typical tetrasporic structures. The most widely reproductive rhodophytes were *Polysiphonia flexicaulis*, *Ceramium rubrum* and *Scagelia pylaisaei*. Reproductive *P. flexicaulis* plants were recorded for the last four study periods, *C. rubrum* for all but the second study period, and *S. pylaisaei* for all but the first study period (Appendix 2). In general, tetrasporic specimens were larger than sterile individuals.

### ***Invertebrates***

Hydroids were assumed to have reproductive potential in all cases where hydranths were observed, indicating healthy organisms. This was not assumed a sign that they were actually reproductive at the time they were sampled. At site 2, most specimens from the middle three study periods lacked hydranths, were heavily microfouled, and appeared dead. All recorded specimens of *Mytilus edulis* were small juveniles, and it is assumed they were not sexually mature.

## **3.4 Biomass Accumulation**

### **3.4.1 Heterogeneity of variance**

Bartlett's test for homogeneity of variance (Bartlett 1937, Little & Hills 1987) indicated that the standard deviations for all three sites were heterogeneous ( $\underline{M} = 37.18$ ,  $\underline{k} = 15$ ,  $\underline{c}_1 = 1.87$ ). An examination of the data by site indicated that heterogeneity occurred at site 3 ( $\underline{M} = 25.86$ ,  $\underline{k} = 5$ ,  $\underline{c}_1 = 0.6$ ), but not at sites 1 and 2 ( $\underline{M} = 7.39$  and  $\underline{M} = 2.12$  respectively,  $\underline{k} = 5$ ,  $\underline{c}_1 = 0.6$ ). Consequently the data for site 3 was considered unreliable, and the analysis of variance of site 3 biomass data was performed independently to the study period level only (Table 8).

### 3.4.2 Analysis of variance (site 3)

The residual column effect (#2, Table 1) was non-significant for each study period ( $F < 10.92$ ) and was combined with total error (#5, Table 1).

**Table 8** Randomized blocks analysis of site 3 log<sub>e</sub> data with combined error terms.  
(\*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; \*\*\*,  $P < 0.001$ )

Study Period	Source	SS	DF	MS	F	P
(1) May/June	Treatment	0.45	1	0.45	2.70	
	Depth	3.88	3	1.29	7.77	*
	Depth x Treatment	0.70	3	0.23	1.41	
	Error	1.33	8	0.17		
	TOTAL	6.36	15			
(2) June/July	Treatment	1.29	1	1.29	163.34	***
	Depth	0.05	3	0.02	2.27	
	Depth x Treatment	0.17	3	0.06	7.18	*
	Error	0.06	8	0.01		
	TOTAL	1.57	15			
(3) July/August	Treatment	1.58	1	1.58	13.96	**
	Depth	0.51	3	0.17	1.48	
	Depth x Treatment	0.30	3	0.10	0.88	
	Error	0.91	8	0.11		
	TOTAL	3.30	15			
(4) August/September	Treatment	$1.3 \times 10^{-6}$	1	$1.3 \times 10^{-6}$	$1.3 \times 10^{-6}$	
	Depth	1.09	3	0.36	8.48	**
	Depth x Treatment	0.19	3	0.06	1.49	
	Error	0.34	8	0.04		
	TOTAL	1.63	15			
(5) September/October	Treatment	0.34	1	0.34	38.69	***
	Depth	0.95	3	0.32	35.42	***
	Depth x Treatment	0.19	3	0.06	7.30	*
	Error	0.07	8	0.01		
	TOTAL	1.56	15			

The subsequent analysis of variance for site 3 revealed some unusual characteristics in the data, particularly the pattern of treatment and depth effects, and their interaction (Table 8). These peculiarities suggest the results of the analysis should be interpreted with caution. The discovery of serious interference by fish farm personnel with the experiment supports this contention.

To summarize, treatment effects for June/July and September/October were highly significant ( $P < 0.001$ ), July/August effects were significant ( $P < 0.01$ ), and May/June and August/September were highly non-significant ( $P > 99.999$ ).

Depth was highly significant for September/October only ( $P < 0.001$ ), significant for August/September ( $P < 0.01$ ), and non significant for the other periods. The *depth*  $\times$  *treatment* interaction was significant for only June/July and September/October ( $P < 0.05$  for both).

### 3.4.3 Analysis of variance (sites 1 & 2)

Neither the residual column effect (#4, Table 2) nor the residual column effect by month interaction (#5, Table 2) were significant, and hence they were combined with the error term (#10, Table 2) prior to analyses (Tables 9 & 10).

### Site 1

The analysis of variance (ANOVA) of site 1  $\log_e$  biomass data showed that Study Period, Treatment, Treatment by Study Period interactions, and Depth were all highly significant ( $P < 0.001$ ) (Table 9).

**Table 9** ANOVA of site 1  $\log_e$  biomass data with combined error. (\*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; \*\*\*,  $P < 0.001$ )

Source	SS	DF	MS	F	P
Study Period	4.70	4	1.18	16.23	***
Treatment	2.60	1	2.60	35.89	***
Treatment x Study Period	3.16	4	0.79	10.90	***
Depth	3.01	3	1.00	13.86	***
Depth x Study Period	1.93	12	0.16	2.22	*
Treatment x Depth	0.90	3	0.30	4.12	*
Treatment x Depth x Study Period	0.31	12	0.02	0.35	
Error	2.90	40	0.07		
Total	19.51	79			

**Table 10** ANOVA of site 2  $\log_e$  biomass data with combined error. (\*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; \*\*\*,  $P < 0.001$ )

Source	SS	DF	MS	F	P
Study Period	6.80	4	1.70	16.90	***
Treatment	1.14	1	1.14	11.31	**
Treatment x Study Period	1.06	4	0.26	2.64	*
Depth	5.40	3	1.80	17.90	***
Depth x Study Period	8.00	12	0.67	6.63	***
Treatment x Depth	0.41	3	0.14	1.37	
Treatment x Depth x Study Period	1.47	12	0.12	1.22	
Error	4.02	40	0.10		
Total	28.30	79			



### ***Site 2***

The ANOVA for site 2 (Table 10) shows that study period, depth, and the study period/depth interaction were highly significant ( $P < 0.001$ ). Both the treatment effect ( $P < 0.01$ ) and treatment/study period interaction ( $P < 0.05$ ) were less significant than at site 1 (Table 9).

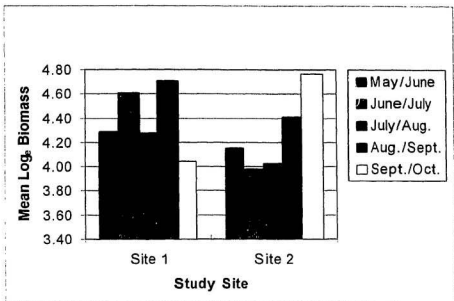
## **3.5 Main Effects**

### **3.5.1 Study period effects**

#### ***Site 1***

At site 1, mean biomass accumulation was greatest at the end of the August/September study period (4.71) and lowest at the end of the September/October period (4.04) (Figure 11). June/July biomass (4.61) was very similar to the August/September value.

June/July and August/September fouling assemblages were characterised by heavy accumulations of relatively dense fouling organisms (primarily *Mytilus edulis* (App. 1, Tables A 1.2 & 1.4). In contrast, September/October assemblages were comprised primarily of less dense algae and hydroids (App. 1, Table 1.5).



**Figure 11** Mean  $\log_e$  mean biomass by study period for sites 1 (HMSC) ( $SE \pm 0.067$ ) and 2 (Jail Island) ( $SE \pm 0.078$ ).

Biomass values for May/June and July/August panels were very close, at 4.29 and 4.28 respectively. However, the composition of corresponding assemblages was markedly different. May/June panels were fouled primarily by algae (App. 1, Table A1.1). In contrast, July/August panels were heavily fouled with juvenile *Mytilus edulis* (App. 1, Table A1.3).

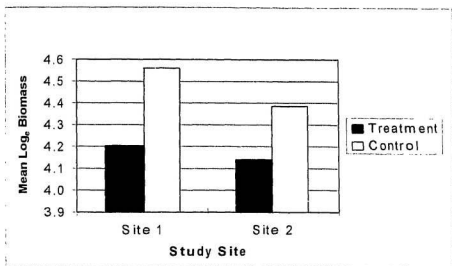
### **Site 2**

The largest mean biomass value at site 2 occurred on the September/October panels ( $\log_e$  mean biomass = 4.77) (Figure 11). The lowest value was recorded for June/July (3.98), although this was only marginally lower than the July/August mean (4.02). May/June and August/September values were 4.15 and 4.41 respectively.

September/October panels were heavily fouled by hydroids (App.1, Table A1.5), the hydrocauli of which comprised a relatively dense, proteinaceous chitin complex. The comparatively lighter June/July and July/August panels had distinctly different fouling assemblages (App.1, Tables A1.2 & 1.3), with the former comprised primarily of algae, whilst the latter had a combination of hydroids, algae and small mussels. Fouling for the two periods with intermediate biomass values, May/June (4.15) and August/September (4.41), was characterised by a mixture of algae and hydroids (App. 1, Tables A1.1 & 1.4).

### **3.5.2 Treatment effects**

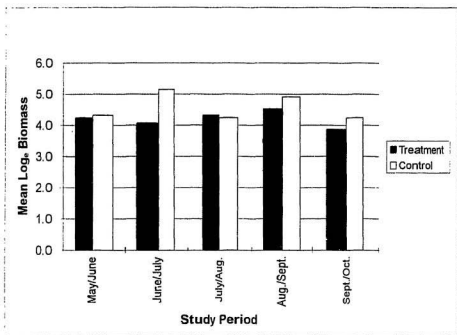
Overall, Easy-Net™ antifouling wax reduced biomass accumulations on net panels (Figure 12). The  $\log_e$  mean biomass for treated and control panels at site 1 were 4.20 and 4.56 respectively. Corresponding site 2 values were 4.14 and 4.39.



**Figure 12** Mean log<sub>e</sub> biomass on treated (Easy-Net™) and control panels at sites 1 (HMSC) (SE  $\pm$  0.043) and 2 (Jail Island) (SE  $\pm$  0.049).

### 3.5.3 Treatment/study period effects

For both sites, the treatment/study period effect was significant, but to different degrees (Figures 13 & 14). At site 1, the effect was highly significant ( $P < 0.001$ ) (Table 9). The significance level of the treatment/study period effect at site 2 was 0.05 (Table 10).

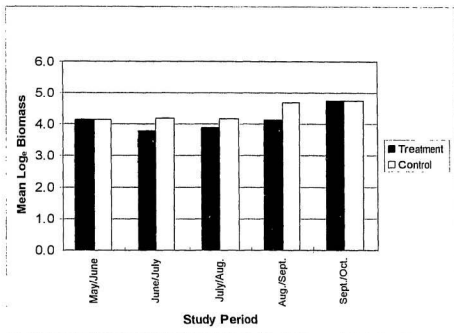


**Figure 13** Site 1 mean log<sub>e</sub> biomass for consecutive study periods ( $SE \pm 0.095$ ) on treated (Easy-Net™) and control panels

### *Site 1*

Mean log<sub>e</sub> biomass treatment values were lower than corresponding controls for all study periods except July/August (Figure 13), where treatment (4.37) was higher than control (4.23). The June/July period showed both the highest biomass accumulation (Control = 5.15) and the greatest difference between treatment and control, with values of 4.07 and 5.15 respectively. May/June treatment (4.25) and control (4.32) values had the least difference. The differences between treatment and corresponding

control values for August/September (4.53 and 4.89 respectively) and September/October (3.86 and 4.22 respectively) were similar.



**Figure 14** Site 2 mean log<sub>e</sub> biomass for consecutive study periods ( $SE \pm 0.111$ ) on treated (Easy-Net<sup>TM</sup>) and control panels

### ***Site 2***

The treatment effect was generally less pronounced at site 2 than at site 1 (Figure 15). The greatest difference between treatment and control biomass occurred for August/September panels (4.13 and 4.69 respectively). Treatment values were also lower than controls for June/July (3.78 and 4.18 respectively) and July/August (4.16 and 3.89 respectively). In contrast, treatment values were not separable from corresponding controls for May/June (4.16 and 4.15 respectively) and September/October (4.78 and 4.75 respectively).

### **3.5.4 Depth effect**

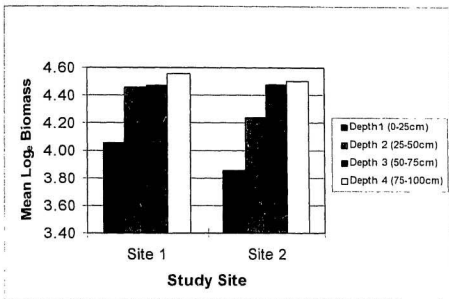
At both sites there was a positive relationship between biomass and depth (Figure 15, Tables 9 & 10).

### ***Site 1***

Biomass values for depths 2 and 3 were very similar, at 4.45 and 4.47 respectively, with the value for depth 4 only slightly higher (4.55). In contrast, the biomass value for depth 1 (4.05) was substantially lower.

### ***Site 2***

At site 2, the differences between biomass values for depths 1,2 and 3 were more pronounced than for site 1 (3.85, 4.23, and 4.47 respectively). Values for depths 3 and 4 were very similar, at 4.47 and 4.50 respectively.



**Fig. 15** Mean  $\log_e$  mean biomass by depth at sites 1 (HMSC) ( $SE \pm 0.060$ ) and 2 (Jail Island) ( $SE \pm 0.070$ ).

### 3.6 Confidence Limits

The calculation of confidence limits (Table 11) at sites 1 and 2 were based on a value of  $t(\alpha, 40)$ . At site 3, because  $s_d$  is based on five distinct error variances (each with 8df), confidence limits were calculated with the 'conservative' value of  $t(\alpha, 8)$ .



**Table 11** % biomass reduction limits for Easy-Net™ antifoulant at the three study sites (99.9% confidence level).

Confidence Level	Site	Limits for $\ln(D)$		Limits for $D$		Limits for % Reduction in Biomass	
		Lower	Upper	Lower	Upper	Lower	Upper
99.9 %	1	-0.5744	-0.1469	0.5631	0.8634	13.66	43.69
	2	-0.4901	-0.0134	0.6126	1.0135	-1.34	38.74
	3	-0.6588	-0.0712	0.5175	0.9312	6.88	48.25

### 3.6.1 Economic decision rule

The ratio of the average 1990 cost of treating a standard enclosure net with Easy-Net™, and the average total annual cost to clean untreated net ( $A/D$ ) was 1.05 ( $A = \$420\text{CDN}$ ;  $D = \$400\text{CDN}$ ). With an average of four changes a year ( $f_c$ ), each 25% reduction in biomass would reduce the number of required net changes by one.

Based on the economic decision rule ( $f_c - f_u > A/D$ ), Easy-Net™ is economically viable if the number of required changes is reduced by at least two ( $f_u \leq 2$ ), representing a 50% reduction in biomass. The upper limits for all sites at the 99.9% confidence level were less

than 50% (Table 11). Therefore, the use of the antifoulant was deemed economically questionable.

## 4. DISCUSSION

The results of this thesis support the observations of salmon farmers. Temporal patterns of local net fouling organisms were similar to those reported by farmers, and the use of a net antifoulant reduced accumulated biomass throughout the study, although it did not significantly affect relative abundance. In addition, the results show that while small-scale spatial variability can occur in net fouling communities, local environmental conditions may affect the character and vigour of communities. Morphological form and size can also be used to infer propagule type, and recruitment mechanisms and periodicity.

### 4.1 Fouling Community Composition

#### 4.1.1 Fouling organisms

The general types of organisms which were described by salmon farmers, namely "slime" (diatoms), "sea grass" (various chlorophytes), "brown hair" (various Ectocarpales), "brown grass" (*Scytosiphon lomentaria*), "wire weed" (hydroids), and mussels (*Mytilus edulis*) were well represented in all five study periods (Appendix 1). The taxa identified are not surprising. They are common members of the local flora (South *et al.* 1988) and fauna (Brinkhurst *et al.* 1976), and are widely recorded as fouling species (WHOI 1952, Fletcher 1980a, Tittley & Fletcher 1984).

The persistence of a number of algae across all study periods (Appendix 1) conflicts with recorded seasonality for corresponding coastal populations (South & Hooper 1980, South

& Tittley 1986, South *et al.* 1988). This may reflect the absence of environmental pressures, such as grazing, desiccation and wave exposure, which can influence the composition of coastal populations (Underwood & Denley 1984, South & Whittick 1987). These types of pressures are likely to be comparatively less extreme on organisms which are attached to floating, submerged net panels than on those colonizing rocky shores.

#### **4.1.2 Temporal Patterns**

There were also close similarities between temporal occurrences of taxa recorded on the net panels (Appendix 1) and those described by farmers. The Ulvaes and Ectocarpales were most prevalent in the first two study periods (spring and early summer), but in later periods the composition was increasingly characterized by hydroids, mussels and the brown alga *Scytosiphon lomentaria*. Unfortunately, with data from only one fouling season it was not possible to compare the apparently cyclic patterns of occurrences between successive years.

#### **4.1.3 Treatment Effects**

In contrast to the extreme limiting effects of organotin antifoulants on fouling community composition, as reported by farmers, the analyses of pooled relative abundance data showed no significant difference in composition between the Easy-Net<sup>TM</sup> treated and untreated nets. Despite the low energy surface characteristics of the wax promoted by the manufacturer, a wide range of organisms were able to colonize the material. This suggests that the product will not gain broad acceptance in the aquaculture

industry. This is particularly so in light of the high performance expectations for antifoulants by salmon farmers who consider anything more than an accumulation of "slime" an indication of poor performance.

#### 4.1.4 Depth Effects

The effect of depth on relative abundance was most pronounced in the green algae, with a general trend of decreasing abundance with depth (Table 7 & Appendix 1). A particularly pronounced depth effect was exhibited by *Ulva lactuca*, a locally common (South *et al.* 1988), typical splash-zone fouling species (WHOI 1952, Terry & Picken 1986). At all three sites it occurred most frequently on upper panels, near the surface of the water.

Generally, the vertical zonation of algae on rocky shores is considered to be expressed over greater depths than the one meter range chosen for this study (Round 1981, Lobban *et al.* 1985, Lüning 1990). At a smaller spatial scale, Fletcher (1980a) recorded a distinct vertical zonation in the relative abundance of a wide variety of algae in 10cm splash-zone bands on floating structures. Considering the potential complexities of developmental processes, and structures of marine communities (Underwood & Denley 1984, Underwood & Fairweather 1989, Vadas *et al.* 1992, Boero 1994), spatial and temporal scales have to be considered when assessing whether patterns are typical or atypical (Underwood & Denley 1984, Roughgarden *et al.* 1988, Santelices 1990, Osman *et al.* 1992, Boero 1994, Osman & Whitlatch 1995). It may be that the type of small-scale

vertical zonation which was recorded for the net panels is typical of short-term, shallow fouling assemblages, but a greater number of observations may be necessary to elucidate spatial and temporal patterns.

The results show that the types of fouling organisms considered to be problematic by salmon farmers typically colonize nets which are suspended in the upper one metre. With respect to the potential for the development of integrated fouling management programs, this characteristic has practical implications. Farmers periodically assess the fouling state of nets visually from walkways, but for the most part their anecdotal observations on fouling composition are derived from more thorough examinations of fouling on entire nets when they are removed from the water for cleaning. Below the algae dominated splash-zone, fouling is predominantly invertebrate, and the composition tends to be fairly uniform at the end of respective two month submersion periods. Therefore, periodic *in situ* assessments of the upper one meter zone, which would indicate both the character of algal fouling in the splash zone and invertebrate fouling on lower regions of the net, may provide sufficient information to be used as the basis for fouling management decisions.

#### **4.1.5 Study period effects**

For the most part, patterns of relative abundance of the algae with respect to significant study period effects (Table 7) were not related to seasonal patterns of occurrence for corresponding coastal populations (Hehre & Mathieson 1970, Mathieson & Hehre 1983, Hoffman 1987, South *et al.* 1988, Whittick *et al.* 1989). For example,

*Enteromorpha intestinalis* was least abundant at the end of the spring study period (end of June), although on the coast this species is normally abundant at this time. Similarly, *E. linza* and *E. prolifera* were typically abundant in the late fall period (end of October), but had a relatively low abundance rating early in the year, despite records of their local prevalence on natural substrates throughout the spring and early summer (South & Tittley 1986, South *et al.* 1988). Species of *Porphyra* occurred quite typically, early and late in the season (South & Tittley 1986, South *et al.* 1988). These results suggest that 'study period effect significance', with respect to algal relative abundance, is unlikely to be related to the vigour of corresponding local coastal populations, and their production of viable propagules. It is more likely to reflect the vagaries of propagule recruitment intensity and post-recruitment mortality on community structure (Underwood & Denley 1984, Boero, 1994), and/or inherent limitations of subjective relative abundance rating.

Amongst the invertebrates, three species showed significant study period effects with respect to relative abundance (Table 7). All generally reproduce seasonally (WHOI 1952, Harris 1990, Seed & Suchanek 1992), but exhibit extended dispersal and recruitment capabilities (Harris 1990, Seed & Suchanek 1992). For example, reproduction in temperate *Mytilus* populations typically occurs in the early spring and late fall (Bayne 1964, Seed & Suchanek 1992), but mussel propagules are planktotrophic and remain capable of pelagic dispersal and recruitment for as long as two months (Lane *et al.* 1985, Lutz & Kennish 1992). With this in mind, the lower abundance of *Mytilus* in the first and last periods (App. 1, Tables A1.1 & 1.5) may not be reflecting variability in reproductive

output, but pre- and post-recruitment mortality (Underwood & Fairweather 1989), or post-emigration densities following juvenile pelagic migration (Lane *et al.* 1982, 1985). Similarly, study period effects exhibited by the hydroids *Tubularia crocea* and *Obelia* sp., may not be solely attributable to their spring and fall reproductive cycles. Both taxa exhibit planktotrophic, pelagic dispersal, and recruitment patterns will reflect these adaptations (Roughgarden *et al.* 1988, Underwood & Fairweather 1989). These persistent dispersive capabilities, the ability to become established rapidly, and presumably a resilience to post-recruitment mortality, all contribute to the prominence of mussels and hydroids as particularly troublesome components of fouling on aquaculture nets.

#### 4.1.6 Site effects

The Kruskal-Wallace analysis is a particularly useful test of site independence, as it indicates a directional shift in median values (Underwood 1981, Goldman & Weinberg 1985). In this case it facilitates the interpretation of site effects from the relative abundance data (Table 7). There was a general pattern of greater abundance at site 1, but this trend may not reflect the particular suitability of local environmental conditions for the development of net fouling. There were some unusual conditions at the Jail Island (site 2), which may have affected the relative abundance and vigour of species. Site 2 is located downstream from an overflow of the Letang pulp mill effluent pond, and there was substantial anecdotal evidence from the operator of the site that the turbidity of the water and the abundance of green “weeds” and diatom “slime” increased substantially following periods of high precipitation. This suggests that run-off from the effluent pond



periodically influenced conditions at the site, although according to the operator there was no apparent detrimental impact on fish production and health. Visually, there seemed to be a general correlation between levels of predominantly diatom microfouling and a lack of vigour in various organisms, particularly *Enteromorpha* spp., *Petalonia fasciata*, *Scytosiphum lomentaria*, and the hydroid *Tubularia crocea*. These species were significantly less abundant at site 2 than at sites 1 and 3, the thalli of the algae had necrotic regions, and many hydroids lacked hydranths. The potential effects of microfouling on the vigour of macrofouling organisms is unclear. There is evidence that benthic diatom accumulations can stimulate the growth of algal recruits (Huang & Boney 1984). Conversely, the deposition of suspended sediments has been reported to have negative effects on survival (Dayton 1975, Neushel *et al.* 1976, Santelices 1990). In contrast to these results, Kennelly (1983) reported positive enhanced survival in the presence of sediments, but this conclusion appears to have a questionable experimental basis (see Santelices 1990). The contradictory evidence in the literature of the effects of microfouling on algal recruitment makes it difficult to differentiate between the periodic release of pulp effluents and microfouling as the possible causes of the lower relative abundances and the lack of vigour of fouling organisms at site 2

## 4.2 Growth Form and Reproductive Status

### 4.2.1 Growth form

### *Algae*

Algal growth form can be a useful indicator of propagule ontology. Small, early-developmental forms such as basally-attached sporelings (e.g. *Enteromorpha* sp. & *Scagelia* sp. in Fig. 4) are most likely to have recruited as spores or other micropropagules. More highly developed and entangled forms (Fig. 6), and small thalli arising from rhizoidal masses (e.g. *Scytosiphon lomentaria* in Fig. 4), are likely to have originated as either spores or entangled 'drift' fragments (Clokic & Boney 1980, Norton 1992). The prevalence of entangled algal forms in all study periods (Appendix 2), and the common occurrence of large, floating mats of dislodged algae in the Passamaquoddy region suggest that entanglement of drifting fragments is a significant colonization mechanism for aquaculture nets. Production of these fragments is largely dependent on hydrodynamic forces (Denny 1988, Santelices 1990), and in light of the extreme tidal forces in the Bay of Fundy (Thurston 1990), sufficient water flow to dislodge and disperse them is likely. Clokic & Boney (1980) make a strong case that coastal waters can be the source of a substantial quantities of algal fragments of a wide variety of species, and fragments of many species have the capability to form attachment structures after recruitment (Round 1981, Kennelly & Larkum 1983, Santelices 1990). This developmental feature makes it difficult to differentiate between plants which originally recruited as spores or fragments.

The latter point is important with regard to the rate of increase of hydrodynamic forces on nets as they become fouled. Size and roughness (surface relief) of fouling organisms

determines drag, which in turn determines resistance to flow, and therefore hydrodynamic loading (see Denny 1988, MTD 1992). Increased roughness and, therefore, hydrodynamic loading are functions of increasing size (Wolfram & Theophanatos 1985, Denny 1988). When substantial quantities of large, morphologically complex algae become entangled in nets, loading increases rapidly. In contrast, the development of organisms from micropropagules leads to more gradual increases in loading. The importance of these differential increases in the rate of hydrodynamic loading on the operational implications of net fouling may be significant. If fouling at a particular location, or at a particular time of year, originates disproportionately as drifting material, and not micropropagules, then there may be substantial, periodic increases in hydrodynamic loads. If it was established that this was the predominant colonization mechanism, it might be worthwhile to consider a physical barrier to catch drift algae before they arrive at the enclosure net.

Another component of hydrodynamic loading calculations for fouling assemblages is the morphological flexibility, or compressibility of constituent organisms (Wolfram & Theophanatos 1985, MTD 1992). Algae and hydroids are considered compressible to varying degrees, whereas organisms with rigid calcareous structures, such as barnacles and mussels are incompressible (Wolfram & Theophanatos 1985, MTD 1992). The lower the degree of compressibility of an assemblage, the greater the hydrodynamic load (MTD 1992).

### ***Invertebrates***

Considering the relative incompressibility of mussels, and related hydrodynamic implications, *en masse* bysso-pelagic migration and recruitment of juvenile mussels (Lane *et al.* 1982, 1985) has the potential to rapidly increase the hydrodynamic loading of nets. Observations of bysso-pelagic migration at site 3 at the end of the June/July period, and the size and the attachment position of juvenile mussels to the surface of underlying fouling (Fig. 9), suggests this is a locally active colonization mechanism. Similarly, the dense, aggregated growth form of hydroids, particularly *Tubularia crocea* (Fig. 8), suggests that gregarious recruitment of larvae (Harris 1990) and localized spread of basal stolons (Brusca & Brusca 1990, Harris 1990, Roberts *et al.* 1991) are active colonization mechanisms. The typical clumped, erect, wirey growth form of hydroids, is moderately compressible (MTD 1992) and, therefore, contributes to a lesser degree than mussels to hydrodynamic loading.

#### **4.2.2 Reproductive status**

The reproductive status of organisms reflects their potential to produce viable propagules which may recruit and develop into reproductive individuals. The reproductive state of fouling organisms, which are attached to nets, will indicate their colonization potential, but not whether colonization will actually occur. Propagules which are produced by net fouling organisms must survive the rigours of dispersal, recruitment and post-recruitment mortality before they become sufficiently well established to

constitute a fouling problem. When clean nets are placed in the water, they immediately become available for colonization by micropropagules, algal fragments and juveniles from the surrounding water. If organisms on adjacent nets or other submerged surfaces are reproductive, they may act as a source of inoculum for clean nets. Also, during net changing, the local quantity of propagules may increase when micropropagules and fragments are dislodged from nets as they are removed from the water.

### *Algae*

As discussed previously, the majority of algae on study panels were reproductive in the first and last two periods, although several were reproductive throughout the study (Appendix 2). These observations offer a confirmation of the typically broad reproductive phenology of the majority of the algae (Hehre & Mathieson 1970, Round 1981, Mathieson & Hehre 1982, Mathieson & Hehre 1983, Lobban *et al.* 1985, Hoffman 1987, Whittick *et al.* 1989, Lüning 1990). These algae have the potential to be the source of propagules, but as discussed, the likelihood of colonizing adjacent structures cannot be predicted.

### *Invertebrates*

Both hydroids and mussels represent a potential source of colonists, although like the algae, the vagaries of recruitment make it impossible to predict how likely they are to infest adjacent structures. Roberts *et al.* (1991) report that hydroid larvae, specifically those of *Tubularia* sp. and *Obelia* sp., recruit rapidly in the immediate

vicinity of parent populations. However, both these species have planktotrophic pelagic dispersal phases, suggesting they are capable of dispersal over larger spatial scales (Scheltema & Carlton 1984, Brusca & Brusca 1990). The reproductive status of hydroids collected from panels during this study was not investigated and, therefore, it wasn't possible to assess their potential to colonize adjacent structures.

Based on the assumption that observed small mussels were sexually immature (Harris 1990, Seed & Suchanek 1992), their potential to colonize adjacent structures was limited to their ability to detach from substrates and disperse pelagically (Bayne 1964, Lane *et al.* 1982, 1985). Again, the likelihood of colonization of adjacent structures depends on largely stochastic juvenile dispersal and recruitment mechanisms. The distances over which pelagic dispersal of juvenile mussels occurs is unknown, but appears to be substantial. Mussels have been observed as common members of geographically isolated offshore fouling communities on the western Scotian Shelf region of the North Atlantic (*pers. observ.*).

#### **4.3 Biomass Accumulation**

Biomass has become a standardized measure of net fouling (Milne 1970, 1975ab, Lovegrove 1979, Sutterlin *et al.* 1981, Hall *et al.* 1989). Although as a measure it does not reflect the hydrodynamic impacts of fouling on nets, it offers the benefits of being easy to collect, and familiar to the aquaculture industry. The industry uses weight for a range of operational measures (*e.g.* production, feed), and biomass-based antifoulant evaluations

are likely to be well received. In addition, the performance of any antifouling with potential to be adopted by the industry is likely to be reflected in biomass data. 'Wet' measures (Milne 1970, 1975ab, Lovegrove 1979, Sutterlin *et al.* 1981, Hall *et al.* 1989) tends to be more variable than 'dry' measures (Weitzel *et al.* 1976) because of variability in the quantity of water retained by the fouling. The methodology for this study minimized this source of error by blotting of each sample according to a standardized protocol. Although this approach does not strictly control errors associated with the retention of water, an unpublished commercial study conducted in 1988 showed similar variances for 'blotted' wet and oven-dried dry fouling accumulations. There are certainly logistic advantages to not having to dry large quantities of fouling organisms in an oven.

#### **4.3.1 Experimental design**

The randomized complete block configuration of net panels in the net frame has the advantage of providing data on relatively large 'stable' quantities of material (Little & Hills 1978). Sub-sampling each net panel provided estimates of the mean and standard deviation of biomass for each study period and site.

Based on the expectation of a positive function between duration of submersion and accumulated biomass (Weitzel *et al.* 1979), and the somewhat skewed distribution of studentized raw data, a log<sub>e</sub> transformation was performed to stabilize the variance (*i.e.* one that does not vary with the mean). A subsequent Bartlett's test revealed heterogeneous variance, which was traced to unusual characteristics of the data for site 3. This was most

likely attributable to interference with experimental units by farm personnel which was only discovered several months after the completion of the field program. Apparently one farm employee repeatedly removed net frames from the water during routine maintenance activities, and left them lying horizontally on cage walkways for unknown periods of time. The magnitude of effects this may have had on the fouling community is unknown, but it is likely to have been some degree of desiccation and possibly dislodgment of organisms which would have affected results. This uncertainty made data from site 3 unreliable for inter-site comparisons.

#### **4.3.2 Analysis of variance (sites 1 & 2)**

##### **Study period effects**

The underlying pattern of study period effects with regard to biomass appears to somewhat reflect the relative densities of constituent organisms. Those with dense morphological features, such as the calcareous shells of mussels, and the chitin/protein hydrocauli of hydroids (Brusca & Brusca 1990, Harris 1990), have a higher relative density than most seaweeds (Denny 1988, MTD 1992). The substantial biomass recorded for August/September panels at site 1 coincided with heavy mussel fouling. Similarly, the highest accumulated biomass at site 2 was recorded for panels fouled primarily by hydroids. Conversely, the lowest biomass values for both sites 1 and 2 were recorded on panels fouled primarily by algae (Appendix 2). It should be noted that this



apparently density-related pattern was not expressed consistently, and on many panels study period effects appeared to be the result of accumulated bulk, and not the respective densities of constituent organisms.

### **Treatment effects**

Easy-Net™ clearly reduced biomass on nets. This result contrasts markedly with the analysis of treatment effects with respect to relative abundance, which showed no significance. It seems reasonable to infer that this contradiction is more likely to reflect limitations of using visual estimates of relative abundance than some unaccounted for anomaly in the biomass data. As discussed, low energy surfaces tend to interfere with both the recruitment of micropropagules, and the entanglement and attachment of seaweed fragments and juvenile mussels (Fletcher & Baier 1984, Callow *et al.* 1986, Santelices 1990, Vadas *et al.* 1992). It is assumed that the low-energy surface presented by the net wax interfered with the recruitment of propagules, which resulted in the lower biomass on treated than untreated nets.

### **Treatment/study period effects**

The effect of the treatment on biomass in particular study periods was more pronounced than treatment effects pooled across study periods. This indicates that some organisms were probably more affected by the presence of the net treatment in some periods than others.

### *Site 1*

The greatest difference in biomass on the treatment and control panels was recorded on the June/July panels, where accumulations of the hydroid *Tubularia crocea* were heavier on control compared to the treated panels (App. 1, Table A1.2). This suggests that the surface properties of the net wax may have had a limiting effect on the establishment and lateral spread of the typical stoloniferous mat of *Tubularia* (Hart's 1990, Roberts *et al.* 1991). The lower biomass on treated compared to control panels for all other periods except July/August, supports the contention that the net treatment interfered with colonization.

### *Site 2*

In general, the treatment effect was less pronounced at site 2 than at site 1. The greatest difference occurred in the August/September data, although there was no obvious compositional difference between the treatment and control assemblages (App. 1, Table A1.4). Similarly, data for the June/July and July/August periods showed some treatment effect, but no obvious corresponding difference in composition (App. 1, Tables A1.2 & 1.3). The occurrence of marginally higher biomass values on treated May/June and September/October panels shows that the effectiveness of the net treatment to limit colonization and growth was not particularly pronounced at site 2. Questions surrounding the potential effects of outflow from an effluent pond and/or the presence of heavy

microfouling on net fouling organisms make it difficult to interpret the relative absence of treatment effects at site 2.

### **Depth effects**

Similar to study period effects, the significant depth effects for both sites 1 and 2 appear to reflect the relative density of constituent organisms. Biomass values for top row panels, which were fouled predominantly by algae, were substantially lower than for the three lower depths, which were fouled primarily by more dense invertebrates. The operational value of these results is limited because the chosen quantitative measure does not reflect the characteristic of fouling, namely resistance to flow, which constitutes the greatest operational problem.

### **4.3.3 Economic Analysis of Easy-Net™**

Easy-Net™ does not appear to reduce biomass sufficiently for there to be much likelihood that producers would use the product. The economic decision (integer) rule indicated a reduction of at least 50% in accumulated biomass would be required for there to be an economic case for using the product. The biomass confidence intervals for all three sites (Table 11) showed that at least 99.9% of the time, the level of biomass reduction will be lower than 50%. These results do not make much of an economic case for the use of Easy-Net™.

The economic analysis is based on an assumption that biomass is a reasonable operational measure of antifouling performance and, therefore, is a viable basis from which to make operational decisions. As discussed, biomass is an attractive measure. Data are fairly straightforward to collect, and the measure is familiar and is used widely by farm operators as an operational measure. Unfortunately, biomass has not been correlated with the fundamental problem associated with net fouling, the restriction of water flow through net mesh (Milne 1970, 1975ab, Bevan 1987, Beveridge 1987).

A more useful measure of fouling would quantify the structural aspects of fouling which determine resistance to water flow. This is a keen interest of structural engineers in the offshore petroleum industry (Wolfram & Theophanotos 1985, MTD 1992), but to date practical solutions to this problem have not been found. The behaviour of marine organisms under the variable flow regimes typical of coastal waters are immensely complex (Denny 1988) and attempts to model and correlate resistance to flow with morphological structure at the community level have been unsuccessful. In the offshore petroleum industry the measurement of fouling has been standardized as a simple measure of increased diameter of fouled components (MTD 1992). The product of the size, percent cover and relative compressibility of constituent organisms are summed to generate a compressed thickness figure (MTD 1992). This approach does not account for the contribution of surface roughness to drag, or resistance to flow. Consequently, resistance to flow must be estimated, and the values which are used tend to be extremely conservative (*per. comm.* Dr. D. Fowler. Brown & Root plc.). At present, the most

promising technique to address these limitations involves the characterization of surface relief, as a measure of relative roughness, using various digital image manipulation techniques. It is hoped that eventually it will be possible to correlate these surface relief 'profiles' with a catalogue of experimentally determined drag forces for various common types of fouling assemblages.

#### **4.4 A Final Note: fouling predictions**

It is increasingly clear that the complexity of benthic community composition and development require substantial experimental and analytical rigor to elucidate even simple changes over time. Regardless, many fouling management strategies are based on a belief that fouling can be predicted (Richardson & Seed 1990, Oshurkov 1992, Zvyagintsev & Ivin 1995). This is not a surprising position considering the potential operational benefits of predicting fouling (*e.g.* planning cleaning cycles and refining structural analyses). It is bolstered by the large body of work which considers fouling development to be ecologically successional (*see* Sousa 1979ab, 1984, Dean & Hurd 1980, Schoener 1984, McCook & Chapman 1991, 1993), and that over-time communities pass through a series of 'predictable' 'stable points' (*see discussion in* Sutherland & Karlson 1977, Sutherland 1984, Underwood & Denley 1984). In light of the widely questioned validity of these perspectives (*see* Sutherland & Karlson 1977, Underwood & Denley 1984, Boero 1994,

Underwood & Anderson 1994), care must be taken not to use operational expediency as the basis for proliferating a belief in empirical predictive capability.

## 5. CONCLUSIONS

This thesis has shown that the sessile marine organisms which foul salmon aquaculture nets in southwestern New Brunswick are common members of the local fauna and flora. It showed that both the quantity and type of organisms changed throughout the summer production period, and that the greatest biomass was contributed by invertebrates, particularly mussels. It also showed that the antifouling wax Easy-Net™ reduced the accumulated biomass of fouling, but insufficiently for the industry to use the product. The net wax did not significantly reduce the relative abundance of organisms.

The work also showed that biomass is not a good measure of fouling. Biomass does not reflect the primary operational concern of fouling, which is increased drag on fouled surfaces. Current research efforts to quantify fouling for operational purposes are primarily concerned with establishing links between the physical structure of fouling communities and drag.

In addition, the thesis has shown that the growth form of net fouling organisms is a good indicator of the type of reproductive propagules which recruit to the nets. The results showed that algae are capable of colonizing nets as spores and vegetative fragments, whereas net fouling invertebrates recruit as larvae and juveniles.

Net fouling patterns reported by salmon farmers were found to be similar to the patterns of fouling recorded for the study nets. This showed that farmers have the ability to distinguish different types of fouling, and suggests that the observations of farmers may be useful to improve net fouling management strategies without the need for specialized assessments. It may be possible to employ fouling thresholds, which are based on farmers' observations of types and levels of fouling, as the basis for fouling management decisions.

However, there has been little interest in the further development of net fouling management strategies since effective copper-based net antifoulants have become widely available. In this light, this thesis has minimal operational relevance.



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## **Appendix 1**

### **Relative abundance data**

**Table A1.1** Relative abundance of macrofouling organisms at the end of study period 1 (May/June) on Easy-Net™ treated (T) and untreated (C) net panels, suspended vertically at four depths (P=present: at least one occurrence; C=common: distinct aggregations; A=abundant: clearly predominant organism(s) on panel)

CLASS Order <i>Genus species</i>	SITE		1 (HMSC)								2 (Jail Island)								3 (Frye Island)								
	DEPTH (cm)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	
<b>ALGAE</b>																											
<b>CHLOROPHYCEAE</b>																											
<b>Cladophorales</b>																											
<i>Cladophora sericea</i> P P																											
<i>Chaetomorpha linum</i> P P																											
<i>Rhizoclonium riparium</i> C P C P P P P P P P																											
<i>Urospora wormskjoldii</i> P P																											
<b>Ulotrichales</b>																											
<i>Ulothrix flacca</i> P P																											
<b>Ulvales</b>																											
<i>Enteromorpha intestinalis</i> P P P C P C P C P P																											
<i>E. linza</i> P P																											
<i>E. prolifera</i> P P																											
<i>Ulva lactuca</i> P P P P P P																											
<i>Ulvaria obscura</i> P P																											
<b>PHAEOPHYCEAE</b>																											
<b>Ectocarpales</b>																											
<i>Ectocarpus siliculosus</i> P P P P P P P P																											
<i>Pilayella littoralis</i> A A A A A A C C C C C C C C C C C C																											
<b>Scytoalipbonales</b>																											
<i>Petalonia fasciata</i> P P P P P P P P																											
<b>RHODOPHYCEAE</b>																											
<b>Bangiales</b>																											
<i>Porphyra miniata</i> P P P P P P P P P P																											
<i>Porphyra</i> sp. P P P P P P P P P P P P P P																											

Continued ...

Table A1.1 continued

CLASS Order Genus species	SITE DEPTH (cm) TREATMENT	1 (HMSC)				2 (Jail Island)				3 (Frye Island)			
		1 (0-25)	2 (25-50)	3 (50-75)	4 (75-100)	1 (0-25)	2 (25-50)	3 (50-75)	4 (75-100)	1 (0-25)	2 (25-50)	3 (50-75)	4 (75-100)
		T C	T C	T C	T C	T C	T C	T C	T C	T C	T C	T C	T C
<b>Ceramiales</b> <i>Polysiphonia flexicaulis</i> <i>Scagelia pylaisiei</i>		P			P		P			P	P P	P	
<b><u>INVERTEBRATES</u></b> <b>HYDROZOA</b> <b>Hydroida</b> <i>Bougainvillea carolinensis</i> <i>Obelia</i> sp. <i>Tubularia crocea</i>							P P	P					
							P P	P P	P P				



**Table A1.2** Relative abundance of macrofouling organisms at the end of study period 2 (June/July) on Easy-Net™ treated (T) and untreated (C) net panels, suspended vertically at four depths. (P=present: at least one occurrence; C=common: distinct aggregations; A=abundant: clearly predominant organism(s) on panel)

CLASS Order <i>Genus species</i>	SITE DEPTH (cm) TREATMENT	1 (HMSC)								2 (Jail Island)								3 (Frye Island)							
		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)	
		T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
ALGAE																									
CHLOROPHYCEAE																									
Acrosiphonales																									
<i>Spongomorpha</i> sp.																									
Cladophorales																									
<i>Cladophora sericea</i>																									
<i>Chaetomorpha linum</i>																									
<i>Rhizoclonium riparium</i>																									
Ulvales																									
<i>Enteromorpha intestinalis</i>																									
<i>E. linza</i>																									
<i>E. prolifera</i>																									
<i>Ulva lactuca</i>																									
PHAEOPHYCEAE																									
Dictyosiphonales																									
<i>Dictyosiphon foeniculaceus</i>																									
Ectocarpales																									
<i>Ectocarpus siliculosus</i>																									
<i>Phyllocladus littoralis</i>																									
Laminariales																									
<i>Laminaria</i> sp.																									
Scytosiphonales																									
<i>Petalonia fasciata</i>																									
<i>Scytosiphon lomentaria</i>																									

Continued...

Table A1.2 continued

		SITE		1 (HMSC)								2 (Jail Island)								3 (Frye Island)							
CLASS	Order	DEPTH (cm)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)	
Genus species		TREATMENT		T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
RHODOPHYCEAE																											
Bangiales																											
Porphyra miniata			P	P	P	P	P																				
Ceramiales																											
Ceramium nodulosum												P	P							P	P			P	P		
Polysiphonia flexicaulis		P	P	P	P	P	P	P	P	P	P			P	P			P	P			P	P	P	P		
Scagelia pylaisi			P	P	P	C	C	C	C																P		
INVERTEBRATES																											
HYDROZOA																											
Hydroida																											
Obelia sp.																							P				
Tubularia crocea		P	A	C	A	C	A	C	A	P	P	P	P	P	P	P											
BIVALVIA																											
Anisomyaria																											
Mytilus edulis				P	P	C	C	C	C											P		P	P	C	C	C	C

**Table A1.3** Relative abundance of macrofouling organisms at the end of study period 3 (July/August) on Easy-Net™ treated (T) and untreated (C) net panels, suspended vertically at four depths (P=present: at least one occurrence; C=common: distinct aggregations; A=abundant: clearly predominant organism(s) on panel)

CLASS Order Genus species	SITE		1 (HMSC)								2 (Jall Island)								3 (Frye Island)							
	DEPTH (cm)	TREATMENT	1		2		3		4		1		2		3		4		1		2		3		4	
			(0-25)	(25-50)	(50-75)	(75-100)	(0-25)	(25-50)	(50-75)	(75-100)	(0-25)	(25-50)	(50-75)	(75-100)	(0-25)	(25-50)	(50-75)	(75-100)	(0-25)	(25-50)	(50-75)	(75-100)	(0-25)	(25-50)	(50-75)	(75-100)
<b>ALGAE</b>																										
<b>CHLOROPHYCEAE</b>																										
<b>Acrosiphonales</b>																										
<i>Spongomorpha</i> sp.		P									P										P					
<b>Cladophorales</b>																										
<i>Cladophora sericea</i>		C	C	P	P	P	P	P	P	P	P	P	P						P	P						
<i>Chaetomorpha linum</i>		P	P	P	P	P				P	P								P	P						
<i>Rhizoclonium riparium</i>			P	P	P					C	C	P	P						C	C	P	P	P	P	P	P
<b>Ulinales</b>																										
<i>Enteromorpha intestinalis</i>		C	C	P	P	P	P	P	P	P	C	P	P	P				C	P	P	P	C	P	C		P
<i>E. linza</i>		P	P	P	P					P	P															
<i>E. prolifera</i>		P	P	P		P																				
<i>Ulva lactuca</i>		P	P	P	P																					
<i>Ulvaria obscura</i>		P	P	P	P																					
<b>PHAEOPHYCEAE</b>																										
<b>Dictyosiphonales</b>																										
<i>Dictyosiphon feniculaceus</i>				P	P	P	P																			
<b>Ectocarpales</b>																										
<i>Ectocarpus siliculosus</i>		P	P	P	P	P	P			P	P	P	P	P					C	P	C		P	P	P	P
<i>Pilayella littoralis</i>		P	P	P	P		P	P		P	P	P	P						C	P	C		P	P	P	P
<b>Laminariales</b>																										
<i>Chorda tomentosa</i>				P	P		P															P				
<b>Scytosiphonales</b>																										
<i>Petalonia fasciata</i>										P	P								P	P		P				P
<i>Scytosiphon lomentaria</i>										P									P	P	P	P				

Continued...

Table A1.3 continued

CLASS	SITE DEPTH (cm)	1 (HMSC)								2 (Jail Island)								3 (Frye Island)							
		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)	
	Order Genus species TREATMENT	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
<b>RHODOPHYCEAE</b>																									
<b>Bangiales</b>																									
<i>P. umbilicalis</i>						P	P																		
<i>Porphyra</i> sp.			P																						
<b>Ceramiales</b>																									
<i>Polysiphonia flexicaulis</i>			P	P	P	P	P	P	P		P	P	C	P	C	P	C	P	A	P	A	C	A	C	A
<i>Scogelia pylatai</i>			P																						
<b>INVERTEBRATES</b>																									
<b>HYDROZOA</b>																									
<b>Hydroids</b>																									
<i>Bougainvillea carolinensis</i>				P	P																				
<i>Obelia</i> sp.																									
<i>Tubularia crocea</i>			P	P	P	P	C		P	P	P	C	C	C	C	C	C		P	C	C	C	C	C	C
<b>BIVALVIA</b>																									
<b>Anatomyaria</b>																									
<i>Mytilus edulis</i>		C	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A								

**Table A1.4** Relative abundance of macrofouling organisms at the end of study period 4 (August/September) on Easy-Net™ treated (T) and untreated (C) net panels, suspended vertically at four depths (P=present: at least one occurrence; C=common: distinct aggregations; A=abundant: clearly predominant organism(s) on panel)

CLASS Order <i>Genus species</i>	SITE		1 (HMSC)								2 (Jail Island)								3 (Frye Island)								
	DEPTH (cm)	TREATMENT	1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		
			T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
<b>ALGAE</b>																											
<b>CHLOROPHYCEAE</b>																											
<b>Acrosiphonales</b>																											
<i>Spongomorpha aeruginosa</i>																											
P																											
P																											
P																											
<b>Cladophorales</b>																											
<i>Cladophora sericea</i>																											
P																											
C																											
P																											
P																											
<i>Chaetomorpha linum</i>																											
P																											
P																											
<i>Rhizoclonium riparium</i>																											
P																											
P																											
<i>Urospora wormskoldii</i>																											
P																											
<b>Ulvales</b>																											
<i>Enteromorpha intestinalis</i>																											
P																											
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<i>E. linza</i>																											
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<i>E. prolifera</i>																											
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<i>Ulva lactuca</i>																											
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P																											
<i>Ulvaria obscura</i>																											
P																											
<b>PHAEOPHYCEAE</b>																											
<b>Chordariales</b>																											
<i>Chordaria flagelliformis</i>																											
P																											
P																											
<b>Dictyosiphonales</b>																											
<i>Dictyosiphon foeniculaceus</i>																											
P																											
<b>Ectocarpales</b>																											
<i>Ectocarpus siliculosus</i>																											
P																											
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<i>Pilayella littoralis</i>																											
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P																											
<b>Scytosiphonales</b>																											
<i>Petalonia fasciata</i>																											
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<i>Scytosiphon lomentaria</i>																											
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Table A1.4 continued

CLASS	SITE DEPTH (cm)	TREATMENT	1 (HMSC)								2 (Jail Island)								3 (Frye Island)											
			1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)		1 (0-25)		2 (25-50)		3 (50-75)		4 (75-100)					
			T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C		
RHODOPHYCEAE																														
Bangiales																														
Porphyra miniata			P	P	P	P	P	P	P	P																				
P. umbilicalis																			P	P	P	P					P			
Porphyra sp.											P																			
Ceramiales																														
Antithamnionella floccosa									P																					
Ceramium nodulosum				P	P	P	P																							
Polysiphonia flexicaulis			P	P	P	P		P	P	P	P	P	P		P		P	P	P	P										
Scagelia pylaisei								P	P												P									
INVERTEBRATES																														
HYDROZOA																														
Hydroida																														
Bougainvilla carolinensis																									P	P				
Obelia sp.			P	P		P	P		P	P	P	P		P	P	P	P		P	P	P	P	P	P	P	P	C	C		
Tubularia crocea						P	P	P	P	P	P		P	C	C	C	C	C	C	P	P	P	P	P	P	P	C	C		
BIVALVIA																														
Anisomyaria																														
Mytilus edulis			A	A	A	A	A	A	A	A					P	P		P				C	C	C	C	A	A			

**Table A1.5** Relative abundance of macrofouling organisms at the end of study period 5 (September/October) on Easy-Net™ treated (T) and untreated (C) net panels, suspended vertically at four depths (P=present: at least one occurrence; C=common: distinct aggregations; A=abundant: clearly predominant organism(s) on panel)

CLASS Order Genus species	TREATMENT	SITE		1 (HMSC)								2 (Jail Island)								3 (Frye Island)							
		DEPTH (cm)		1		2		3		4		1		2		3		4		1		2		3		4	
		(0-25)		(25-50)		(50-75)		(75-100)		(0-25)		(25-50)		(50-75)		(75-100)		(0-25)		(25-50)		(50-75)		(75-100)		(0-25)	
		T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
<b>ALGAE</b>																											
<b>CHLOROPHYCEAE</b>																											
<b>Cladophorales</b>																											
<i>Cladophora sericea</i>		P	P	P		P	P			P	P									P	P	P					
<i>Chaetomorpha linum</i>				P																							
<i>Rhizoclonium riparium</i>		P	P					P	P	C	P	P		P						C	C	P	P	P	P		
<b>Ulvales</b>																											
<i>Blidingia</i> sp.		P			P	P	P	P	P																		
<i>Enteromorpha intestinalis</i>		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	A	C	C	C	P	P	P	P
<i>E. linza</i>		C	C	A	A	P	C	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P				
<i>E. prolifera</i>		P	P	C	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P				
<i>Ulva lactuca</i>		P	P																	P	P						
<i>Ulvaria obscura</i>		P																									
<b>PHAEOPHYCEAE</b>																											
<b>Ectocarpales</b>																											
<i>Ectocarpus siliculosus</i>		P	P	P	P	C	P	C	C	P	P									P	P	P	P	P	P	P	P
<i>Pilayella littoralis</i>		P	P	C	P	C	P	C	C	P	P									P	P	P	P	P	P	P	P
<b>Scytosiphonales</b>																											
<i>Petalonia fascia</i>		P	P	P	P	P	P	P		C	P		P							P	P		P				
<i>Scytosiphon lomentaria</i>		P	P		P			P		P	P		P							P	P	P	P	C	P	P	P
<b>RHODOPHYCEAE</b>																											
<b>Bangiales</b>																											
<i>Porphyra miniata</i>				P	P		P																				
<i>P. umbilicalis</i>																											
<i>Porphyra</i> sp.		P		P	P					P	P																

Continued...

Table A1.5 continued

[illegible]



## **Appendix 2**

**Descriptions of growth form and reproductive status**

**Table A2.1** Descriptive summary of growth form and reproductive status of constituent fouling organisms at the end of the May/June study period. (Reproductive status: H = hermaphroditic; P = plurilocular reproductive structures; S = sterile; U = unilocular reproductive structures; Z = zoosporic)

CLASS Order Genus species	SITES	GROWTH FORM	REPRODUCTIVE STATUS
<b>ALGAE</b>			
<b>CHLOROPHYCEAE</b>			
<b>Cladophorales</b>			
<i>Chaetomorpha linum</i>	1,2,3	- long loosely entwined filaments & short, fine basally-attached filaments	S
<i>Cladophora sericea</i>	1	- branched entangled thalli / no attachment points observed	S
<i>Rhizoclonium riparium</i>	1,2,3	- loosely entwined long thin filaments & dense entangled clumps	S
<i>Urospora wormskoldii</i>	2	- long loosely entangled filaments	S
<b>Ulotrichales</b>			
<i>Ulothrix flacca</i>	1,2	- loosely entangled filaments / no attachment points observed	S
<b>Ulvales</b>			
<i>Enteromorpha intestinalis</i>	1,2,3	- dense entangled aggregations & scattered individual thalli (1-10cm long)	S,Z
<i>E. linza</i>	1	- basally-attached, loosely entangled short individual thalli (1-5cm long)	S
<i>E. prolifera</i>	1	- long, branched entangled thalli / no attachment points observed	S
<i>Ulva lactuca</i>	1,2,3	- scattered small blades (2-5cm diameter)	S
<i>Ulvaria obscura</i>	1,2	- scattered small blades (1-3 cm long)	S
<b>PHAEOPHYCEAE</b>			
<b>Ectocarpales</b>			
<i>Ectocarpus siliculosus</i>	1,2,3	- fairly evenly distributed entangled thalli / mixed with <i>P. littoralis</i> / heavily microfouled	P,S,U
<i>Phyllocladus littoralis</i>	1,2,3	- fairly evenly distributed entangled thalli / mixed with <i>E. siliculosus</i> / heavily microfouled	H,P,S,U
<b>Scytosiphonales</b>			
<i>Petalonia fascia</i>	1,2	- scattered aggregations of small, basally-attached blades (1-3cm long) / heavily microfouled	
<b>RHODOPHYCEAE</b>			
<b>Bangiales</b>			
<i>Porphyra</i> sp.	1,2,3	- scattered small individual blades (0.5-2cm long) / heavily microfouled	S

Continued...

Table A2.1 continued

CLASS	SITES	GROWTH FORMS	REPRODUCTIVE STATUS
Order			
Genus/species			
<b>Ceramiales</b>			
<i>Polysiphonia flexicaulis</i>	1,3	- scattered small (1-2cm long) rigid, basally-attached arborescent, tenaciously attached individuals	S
<i>Scogelia pylaisii</i>	1,2	- scattered small ( $\leq$ 1cm long) basally-attached highly branched plumose individuals	S
<b>INVERTEBRATES</b>			
<b>HYDROZOA</b>			
<b>Hydroids</b>			
<i>Bougainvillea carolinensis</i>	2	- small ( $\leq$ 3cm long) branched twig-like individuals	-
<i>Tabularia crocea</i>	2	- small ( $\leq$ 4cm long) wiry clumps	-

**Table A2.2** Descriptive summary of growth form and reproductive status of constituent fouling organisms at the end of the June/July study period. (Reproductive status: P = plurilocular reproductive structures; S = sterile; T = tetrasporic; U = unilocular reproductive structures; Z = zoosporic)

CLASS				
Order	SITE	GROWTH FORM	REPRODUCTIVE STATUS	
<i>Genus species</i>				
<b>ALGAE</b>				
<b>CHLOROPHYCEAE</b>				
<b>Acrosiphonales</b>				
<i>Spongomorpha</i> sp.	1,2	- scattered small (2-4cm long) highly branched, tenaceous, basally-attached tufts		S
<b>Cnidophorales</b>				
<i>Cladophora sericea</i>	1,2,3	- moderately dense entangled aggregations & highly branched loosely entangled filaments / no attachment points observed		S
<i>Chaetomorpha linum</i>	1,2,3	- long loosely entwined filaments / no attachment points observed		S
<i>Rhizoclonium riparium</i>	1,2,3	- dense entangled clumps, moderately dense entangled aggregations & loosely entwined filaments / no attachment points observed		S
<b>Ulvales</b>				
<i>Enteromorpha intestinalis</i>	1,2,3	- various lengths (2-10cm) of basally-attached, free-floating unentangled thalli & entangled thalli with no obvious attachment points		S
<i>Ulva lactuca</i>	1,2,3	- a range of sizes of thalli (2-10cm diameter)		Z
<b>PHAEOPHYCEAE</b>				
<b>Dictyosiphonales</b>				
<i>Dictyosiphon foeniculaceus</i>	1,3	- scattered small (2-5cm long) basally-attached wirey arborescent thalli		S
<b>Ectocarpales</b>				
<i>Ectocarpus siliculosus</i>	1,2,3	- entangled thalli / mixed with <i>P. littoralis</i> / heavily microfouled (sites 2&3)		P,S
<i>Pilayella littoralis</i>	1,2,3	- aggregated entangled thalli / mixed with <i>E. siliculosus</i> / heavily microfouled (sites 2&3)		P,S,U
<b>Laminariales</b>				
<i>Laminaria</i> sp.	3	- isolated, small (3-5cm), basally-attached blades		S
<b>Scytosiphonales</b>				
<i>Petalonia fascia</i>	1,2,3	- scattered small (1-3cm long) basally-attached sporelings & larger (2-5cm) basally-attached aggregations / larger thalli were somewhat necrotic and heavily microfouled		S
<i>Scytosiphon lomentaria</i>	3	- long (5-25cm) basally-attached densely aggregated thalli		S
	2	- small (1-5cm) basally-attached sporelings / smwhat necrotic and heavily microfouled		

Continued...

Table A2.2 continued

CLASS Order Genus species	SITE	GROWTH FORM	REPRODUCTIVE STATUS
<b>RHODOPHYCEAE</b>			
<b>Bangiales</b>			
<i>Porphyra miniata</i>	1	- scattered thalli (2-10cm diameter)	S
<b>Ceramiales</b>			
<i>Ceramium nodulosum</i>	3	- scattered small (1-2.5cm) basally-attached wiry thalli	T
<i>Polysiphonia flexicaulis</i>	1,2,3	- large (>15cm long) tenacious, basally-attached individuals - smaller (2-10cm long) tenacious, basally-attached individuals - moderately dense aggregations on small (1-3cm long) basally-attached plumose specimens - scattered small (1-3cm) plumose basally-attached thalli	T S S S
<i>Scagelina pylaiaei</i>	1 2,3		
<b>INVERTEBRATES</b>			
<b>HYDROZOA</b>			
<b>Hydroids</b>			
<i>Obelia</i> sp.	3	- scattered small (3-5cm) typically arborescent twig-like specimens	-
<i>Tubularia crocea</i>	1	- small (2-4cm long) wiry aggregations	-
	2	- small (2-4cm long) wiry aggregations / heavily microfaunaed and lacking hydranths	-
<b>BIVALVIA</b>			
<b>Anomyaria</b>			
<i>Mytilus edulis</i>	1,3	- scattered (upper panels) and aggregated (lower panels) of juveniles (0.2-0.8cm long) attached to net and hydroids	-

**Table A2.3** Descriptive summary of growth form and reproductive status of constituent fouling organisms at the end of the July/August study period. (Reproductive status: P = plurilocular reproductive structures; S = sterile; T = tetrasporic; U = unilocular reproductive structures)

CLASS	SITE	GROWTH FORM	REPRODUCTIVE STATUS
Order			
<i>Genus species</i>			
<b>ALGAE</b>			
<b>CHLOROPHYCEAE</b>			
<b>Acroisiphonales</b>			
<i>Spongomorpha</i> sp.	1,2,3	- isolated small (2-4cm) tufts / all but distal regions of thalli heavily microfouled	S
<b>Cladophorales</b>			
<i>Cladophora sericea</i>	1	- dense entangled clumps / no attachment points observed	S
	1,2,3	- loosely entangled filaments / no attachment points observed	S
<i>Chaetomorpha linum</i>	1,2,3	- loosely entangled filaments / no attachment points observed	S
<i>Rhizoclonium riparium</i>	2,3	- thick wirey entangled mats / no attachment points observed	S
	1,2,3	- scattered loosely entangled filaments / no attachment points observed	S
<b>Ulvales</b>			
<i>Enteromorpha intestinalis</i>	1,2,3	- various lengths (5-25cm): basally-attached unentangled thalli & unattached entangled thalli	S
	2	- dense aggregations of moderately long (10-20cm) basally-attached entangled thalli	S
<i>E. linza</i>	1,2	- scattered small (2-4cm) basally-attached thalli	S
<i>E. prolifera</i>	1	- scattered entangled thalli / no attachment points observed	S
<i>Ulva lactuca</i>	1	- attached moderately large (5-15cm diameter) blades	S
<i>Ulvaria obscura</i>	1	- scattered small (3-8cm) basally attached thalli	S
<b>PHAEOPHYCEAE</b>			
<b>Dictyosiphonales</b>			
<i>Dictyosiphon foeniculaceus</i>	1	- scattered moderately small (2-10cm long) basally-attached unentangled arborescent individuals	S
<b>Ectocarpales</b>			
<i>Ectocarpus siliculosus</i>	1	- aggregated entangled thalli / mixed with <i>P. littoralis</i>	P,S,U
	2,3	- aggregated entangled thalli / mixed with <i>P. littoralis</i> / heavily microfouled (sites 1&3)	S
<i>Playella littoralis</i>	1	- aggregated entangled thalli / mixed with <i>E. siliculosus</i>	P,S,U
	2,3	- aggregated entangled thalli / mixed with <i>E. siliculosus</i> / heavily microfouled (sites 2&3)	S
<b>Laminariales</b>			
<i>Chorda tomentosa</i>	1,3	- isolated, long (20-60cm), basally-attached, unentangled thalli	S
<b>Scytosiphonales</b>			
<i>Petalonia fascia</i>	2,3	- aggregated small (2-6cm) basally-attached thalli / necrotic and heavily microfouled at site 2	S
<i>Scytosiphon lomentaria</i>	2,3	- various lengths (5-25cm) basally-attached thalli both entangled & unentangled	S

Continued

Table A2.3 continued

CLASS	SITE	GROWTH FORM	REPRODUCTIVE STATUS
<b>Order</b> Genus species			
<b>RHODOPHYCEAE</b>			
<b>Bangiales</b>			
<i>P. umbilicalis</i>	1	- scattered small (2-5cm) attached thalli	S
<i>Porphyra</i> sp.	1	- scattered small (0.5-2cm) sporlings	S
<b>Ceramiales</b>			
<i>Polysiphonia flexicaulis</i>	1,2,3	- a range of sizes (0.5-15cm) basally-attached tenacious arborescent thalli	T
<i>Scogelia pyralis</i>	1	- aggregated small (0.5-2cm) basally-attached plumose individuals	T
<b>INVERTEBRATES</b>			
<b>HYDROZOA</b>			
<b>Hydrula</b>			
<i>Bougainvillea carolinensis</i>	1	- scattered moderately small (5-10cm) basally-attached highly branched colonies	-
<i>Tubularia crocea</i>	1,3 2	- small (3-4cm) wirey tufts - small (3-4cm) wirey tufts / heavily microfouled and lacking most hydranths	- -
<b>BIVALVIA</b>			
<b>Anomomyaria</b>			
<i>Mytilus edulis</i>	1,2	- aggregated juveniles (0.1-1cm long valves) attached to net and fouling	-

**Table A2.4** Descriptive summary of growth form and reproductive status of constituent fouling organisms at the end of the August/September study period. (Reproductive status: P = plurilocular reproductive structures; R = reproductive (phase/generation undetermined); S = sterile; T = tetrasporic; U = unilocular reproductive structures; Z = zoosporic; ? = morphological detail obscured by microfouling)

CLASS Order Genus species	SITE	GROWTH FORM	REPRODUCTIVE STATUS
<b>ALGAE</b>			
<b>CHLOROPHYCEAE</b>			
<b>Acrosiphonales</b>			
<i>Spongomorpha aeruginosa</i>	2	- aggregated, small (3-5cm), basally-attached tufts / heavily microfouled	S
	3	- scattered, small (3-5cm), basally-attached tufts	S
<b>Cladophorales</b>			
<i>Cladophora sericea</i>	1,2,3	- widely distributed, loosely entangled filaments / no attachment points observed	R
<i>Chaetomorpha linum</i>	1,3	- scattered, loosely entangled filaments	R
<i>Rhizoclonium riparium</i>	1	- scattered, thick, wirey entangled clumps / no attachment points observed	R
	1,2,3	- scattered, loosely entangled filaments / no attachment points observed	P
<b>Ulvales</b>			
<i>Enteromorpha intestinalis</i>	1,2,3	- widely distributed, moderately long (4-15cm), basally-attached, entangled thalli	Z
<i>E. linza</i>	3	- scattered, moderately long (4-10cm), basally attached, entangled & unattached, entangled blades	Z
<i>E. prolifera</i>	3	- aggregated and scattered, moderately long (4-10cm), basally-attached, entangled & unattached, entangled blades	Z
<i>Ulva lactuca</i>	1,3	- a range of scattered, moderately small (5-12cm diameter), attached thalli	Z
<i>Ulva obscura</i>	3	- scattered, moderately small (5-8cm), attached blades	S
<b>PHAEOPHYCEAE</b>			
<b>Chordariales</b>			
<i>Chordaria flagelliformis</i>	1,3	- scattered, small (2-8cm long), individual, basally-attached, unentangled, cord-like thalli	S
<b>Dictyosiphonales</b>			
<i>Dictyosiphon foeniculaceus</i>	3	- scattered, typically-branched, unentangled, basally-attached thalli (3-10cm long)	S
<b>Ectocarpales</b>			
<i>Ectocarpus siliculosus</i>	1	- scattered, dense, entangled accumulations	P,S
	2,3	- scattered, dense, entangled accumulations / heavy microfouling	?
<i>Pilayella littoralis</i>	1	- scattered, dense, entangled accumulations	P, S, U
	2,3	- scattered, dense, entangled accumulations / heavy microfouling	?

Continued...



Table 12.4 continued

CLASS	SITE	GROWTH FORM	REPRODUCTIVE STATUS
<b>Order</b>			
<i>Genus species</i>			
<b>Scytosiphonales</b>			
<i>Petalonia fasci</i>	1,3	- scattered aggregations of a range of sizes of basally-attached thalli (2-10cm long)	S
	2	- scattered aggregations of small basally-attached sporlings (2-5cm long)	S
<i>Scytosiphon lomentaria</i>	1,2	- scattered aggregations of moderately long ( $\leq 20$ cm) basally-attached unentangled thalli	S
	3	- dense, heavily entangled aggregations of long ( $\leq 40$ cm) basally-attached thalli	S
<b>RHODOPHYCEAE</b>			
<b>Bangiales</b>			
<i>Porphyra miniata</i>	1,3	- a range of sizes (3-10cm diameter) of scattered, attached, thalli	S
<i>P. umbilicalls</i>	3	- isolated specimens of large ( $\leq 15$ cm diameter) attached specimens	S
	2	- scattered, small (1-2cm), basally-attached sporlings	S
<i>Porphyra</i> sp.			
<b>Ceramiales</b>			
<i>Antithamniomella floccosa</i>	1	- scattered, small (1-3cm), basally-attached, plumose thalli	S
<i>Ceramium nodulosum</i>	1	- scattered, small (1-4cm), erect, basally-attached, typically branched thalli	T
<i>Polysiphonia flexicaulis</i>	1,2,3	- a range of sizes (2-30cm long) of erect, tenaceous, basally attached, entangled and unentangled arborescent thalli	S,T
<i>Scogelia pylvaisi</i>	1,3	- scattered small (1-3cm), erect, basally-attached specimens	T
<b>INVERTEBRATES</b>			
<b>HYDROZOA</b>			
<b>Hydroids</b>			
<i>Bougainvillea carolinensis</i>	3	- scattered moderately small (3.5-8cm) basally-attached highly branched colonies	-
<i>Obelia</i> sp.	1,2,3	- scattered small (3-5cm) typically arborescent twig-like colonies	-
<i>Tubularia crocea</i>	1,3	- small (3-4cm), wirey aggregations	-
	2	- small (3-4cm) wirey tufts / heavily microfouled and lacking most hydranths	-
<b>BIVALVIA</b>			
<b>Anchoyaria</b>			
<i>Mytilus edulis</i>	1,2,3	- aggregated juveniles (0.1-0.5cm long valves) attached to net and fouling	-

**Table A2.5** Descriptive summary of growth form and reproductive status of constituent fouling organisms at the end of the September/October study period. (Reproductive status: P = plurilocular reproductive structures; S = sterile; T = tetrasporic; U = unilocular reproductive structures; Z = zoosporic; ? = morphological detail obscured by microfouling)

CLASS	SITE	GROWTH FORM	REPRODUCTIVE STATUS
Order			
<i>Genus species</i>			
<b>ALGAE</b>			
<b>CHLOROPHYCEAE</b>			
<b>Cladophorales</b>			
<i>Cladophora sericea</i>	1,2	- scattered loosely entangled filaments	S
	1,2,3	- moderately dense, entangled aggregations	S
<i>Chaetomorpha linum</i>	1	- isolated, dense, entangled aggregation	S
<i>Rhizoclonium riparium</i>	1,2	- scattered, loosely entangled filaments	S
	3	- scattered, dark green, coarse, entangled clumps	S
<b>Ulvales</b>			
<i>Blidingia</i> sp.	1	- isolated, attached specimen	S
<i>Enteromorpha intestinalis</i>	1,2,3	- long (entanglement prevented direct measurement), heavily entangled, basally-attached & unattached thalli	S
<i>E. linza</i>	1,2,3	- long, entangled, basally-attached & unattached thalli	Z
<i>E. prolifera</i>	1,2,3	- scattered, thick, entangled aggregations	S
	1,2,3	- scattered loosely entangled thalli	S,Z
<i>Ulva lactuca</i>	1,3	- scattered, attached thalli (< 10cm diameter)	Z
<i>Ulvaria obscura</i>	1	- isolated, moderately small (4-8cm) basally-attached specimens	S
<b>PHAEOPHYCEAE</b>			
<b>Ectocarpales</b>			
<i>Ectocarpus siliculosus</i>	1,	- aggregated entangled thalli / mixed with <i>P. littoralis</i>	P,S,U
	2,3	- aggregated entangled thalli / mixed with <i>P. littoralis</i> / heavily microfouled	P, ?
<i>Platylia littoralis</i>	1	- aggregated entangled thalli / mixed with <i>E. siliculosus</i>	P,S,U
	2,3	- aggregated entangled thalli / mixed with <i>E. siliculosus</i> / heavily microfouled	P, ?
<b>Scytosiphonales</b>			
<i>Petalonia fasciata</i>	2	- dense aggregations of small (2-6cm long), basally-attached thalli	S
	1,2,3	- scattered, larger (3-8cm long), basally-attached, blades	S
<i>Scytosiphon lomentaria</i>	1,2,3	- scattered, long (<225cm), basally-attached, unentangled thalli & extremely dense aggregations of long interwoven, entangled thalli / heavy microfouling at site 2	S

Continued....

Table A2.5 continued

CLASS	SITE		GROWTH FORM	REPRODUCTIVE STATUS
Order				
Genus species				
<b>RHODOPHYCEAE</b>				
<b>Bangiales</b>				
<i>Porphyra miniata</i>	1	- scattered, small (4-5cm diameter), attached specimens		S
<i>Porphyra</i> sp.	1	- scattered, small (1-2cm), basally-attached, extremely delicate sporelings		S
<b>Ceramiales</b>				
<i>Polysiphonia flexicaulis</i>	1,2,3	- two distinct size classes (2-10cm & 15-20cm), tenaceous, basally-attached, typically arborescent, erect thalli		S,T
<i>Scogelia pylaisei</i>	1,3	- scattered, small (1-3cm), erect, plumose thalli		S,T
	3	- aggregated, small (1-3cm), erect, plumose thalli		S,T
<b><u>INVERTEBRATES</u></b>				
<b>HYDROZOA</b>				
<b>Hydroids</b>				
<i>Obelia</i> sp.	1,2,3	- aggregated, moderately small (3-5cm), typically arborescent twig-like colonies		-
<i>Tubularia crocea</i>	1,2,3	- der. : wirey aggregations (≤ 4cm long) / brightly coloured hydranths at all sites		-
<b>BIVALVIA</b>				
<b>Anisomyaria</b>				
<i>Mytilus edulis</i>	1	- aggregated juveniles (0.2-0.5cm long valves) attached to net and fouling		-







